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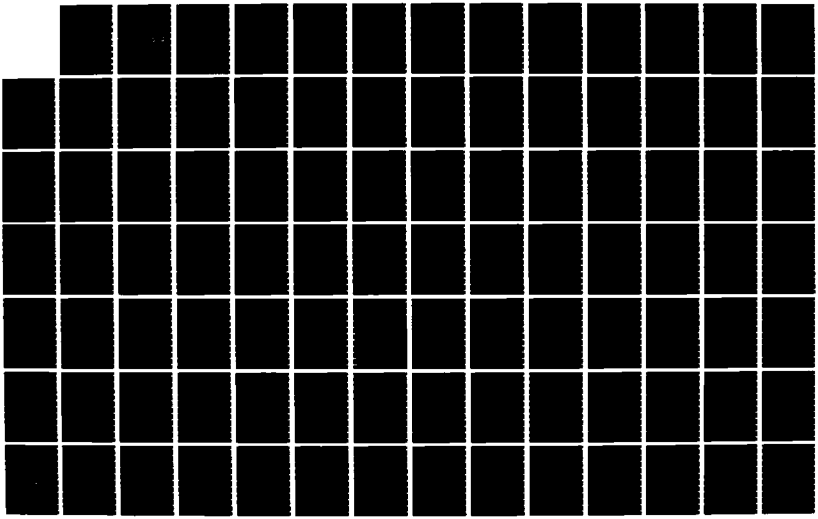

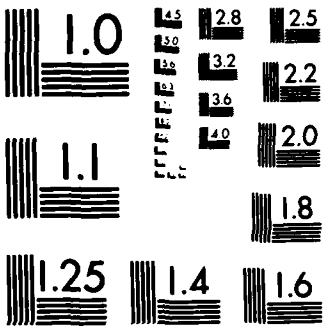

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A FUNCTIONAL EXAMINATION OF

INTERMEDIATE COGNITIVE PROCESSES

David Bruce Porter

Merton College

A thesis submitted for the degree of Doctor of Philosophy

from the University of Oxford

Trinity Term, 1986

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The things I've done best, I've done with others. This thesis is no exception. My writing reflects the influences of teachers, family, friends and colleagues in ways I cannot recount. However, three special acknowledgements are essential.

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A FUNCTIONAL EXAMINATION OF INTERMEDIATE COGNITIVE PROCESSES

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A thesis submitted for the degree of Doctor of Philosophy from the University of Oxford, Trinity Term, 1986.

ABSTRACT

This thesis contains a functional examination of the cognitive processing which occurs between the acquisition of representations and the execution of responses. Three separate types of processing are proposed: explicit self-instruction, general non-verbal concentration and automatic parameter specification by extant knowledge structures. "Save the Whale", a specially developed, arcade type computer game was used to gather information relevant to this conceptual model. The game involved two substantively different but peripherally similar tasks. One task was simple but uncertain and the other was complex but certain. The validity of subjects' post-game verbal accounts of appropriate strategies for the two tasks differed considerably. Subjects' espoused strategies for the simple task were completely consistent with their actual performance. In contrast, their espoused strategies for the complex task were clearly incompatible with their behaviour during the game. Additionally, subjects unanimously nominated the complex task as being the more "difficult".

The central findings of this thesis concern the differential influence of several exogenous factors on the performance of the two game tasks. Both tasks showed strong positive effects from priority instructions and practice. However, verbal side tasks which interfered markedly with the uncertain task had a slightly facilitatory effect on the complex task. Paced, randomly generated articulation, a side task requiring general processing resources, caused almost identical interference with the two tasks initially. However, after 30 minutes, significant interference with the uncertain task continued but had completely disappeared from the complex task. A side task requiring only frequent verbal responses did not interfere with either task.

The implications of these findings are discussed both in terms of alternative conceptualizations of the human information processing system and the structure of knowledge. The particular type of intermediate cognitive processing appears to depend critically on 1) the type of task, 2) the amount of practice and 3) the type of concurrent task. It is also argued that implicit and explicit knowledge are represented better by somewhat independent data bases than by seperate retrieval systems operating on a common data base.

A FUNCTIONAL EXAMINATION OF INTERMEDIATE COGNITIVE PROCESSES

EXTENDED ABSTRACT

Intermediate cognitive processes are the conceptual functions lying between the acquisition of representations and the execution of responses. The distinction between knowledge (the stored symbolic representations of external relation-structures) and attentional resources (the agnostic cognitive mechanisms which actively transform representations) is an initial cleavage within intermediate processes. Both knowledge and resources can be divided further. The difference between the knowledge implied by regularities in performance (i.e., implicit knowledge) and that which can be reported verbally (i.e., explicit knowledge) is of fundamental importance. Similarly, attentional resources can be usefully segregated into two types: those which operate on only verbal material (i.e., the articulatory loop) and those which can process many different types of information (i.e., the central executive).

The human information processing system can be understood best in its natural context: the motivated performance of substantive tasks. At least a tacit understanding of task demands is an important prerequisite to the empirical study of performance. Tasks can be represented as sets of parameters; performance of a task necessarily involves the specification of each of the task's parameters. A task's complexity is reflected by the number of parameters it contains and its uncertainty by the average rate at which the parameters must be specified or respecified. Increases in either complexity or uncertainty generate additional processing demands. Regardless of the type of demand, parameter specification

is the conceptually unique function of intermediate cognitive processes. The model developed in Chapter One of this thesis suggests three distinct sources of parameter specification: 1) direct verbal mediation by attentional resources (i.e., explicit self-instruction), 2) active non-verbal attentional mediation (i.e., concentration) and 3) passive, relatively automatic specification by implicit knowledge (i.e., intuition).

Chapter Two describes the derivation of a somewhat novel psychological instrument. "Save the Whale", an arcade-type computer game, was developed specifically for these experiments. During the game, subjects used a computer keyboard to control the movements of a blue whale. Within the borders of the video screen, the whale moved one space either horizontally or vertically every 700 msec. Subjects could score points in two ways: 1) by eating plankton or 2) by forcing eskimos in kayaks to crash into icebergs. If the eskimos did not crash, they reached the whale and harpooned it; points were lost for this unhappy consequence. Plankton-eating was designed to be a simple but uncertain task. In contrast, kayak-crashing was a complex but certain task. The relative importance of these two tasks was stipulated by priority instructions before each trial and the assignment of different points to each event. Each trial lasted about two and a half minutes or 218 computer "cycles".

A four-choice reaction task and training activity were used to familiarize subjects with the keyboard controls and also provided one measure of individual differences. The experiments involved between 15 and 27 game trials. Each subject completed an equal number of the three priority conditions (i.e., plankton,

equal and kayak) in a fixed rotation. Incidental-learning questions, subjective ratings of the priority conditions, espoused strategies and an embedded figures test provided other individual difference measures.

Using computer games allows one to measure many aspects of performance objectively and unobtrusively. Chapter Three discusses issues relating to measurement and analysis. A rational hierarchy was employed to structure collateral measures of intention, action and motor output system activity in relation to the two task criteria. The exploratory nature of the research, the multiplicity of measures and predominance of interval-scaled data all indicated the use of multiple regression analysis. Three separate, but convergent statistical examinations of the data were chosen. A modified path-analytic procedure was used to identify objective structure relations underlying game performance. Separate simple regression analyses of subjects' performance averages were accomplished to show the influence of individual differences on between-subjects variance. Performance measures were then standardized by-subject and examined by specially-adapted regression procedures for repeated measures designs.

Chapters Four through Eight describe five separate experiments. Experiments One and Two were elaborate pilot studies. The paucity of a relevant literature left many preliminary but necessary questions unanswered. The game, supportive experimental procedures and appropriate data analyses were all developed during these initial experiments. The three subsequent experiments dealt with more substantive issues. Experiment Three incorporated a verbal side task involving the subvocal rehearsal and report of

letter strings to generate patterns of interference in the two game tasks. In Experiment Four, side tasks involving either fixed or randomly-generated sequences of paced verbal responses were employed. The final experiment involved the direct manipulation of cognitive resources and an unpaced, fixed-sequence articulatory side task. Each experiment will be discussed briefly.

Experiments One and Two provided a foundation for subsequent studies. Determining the appropriate operational value for each game component was crucial. The control and display characteristics of the whale; the number, size and position of iceberg clusters; the plankton's starting position and "randomness" of its path; and the number and regularity of appearance of the kayaks as well as general questions concerning the game's pace and duration were all important. The best indication that appropriate values for these parameters had been found was the coherence of the empirical results.

By the end of Experiment Two, all three analyses were yielding relatively cogent and compatible results. The hierarchical structure of collateral performance measures was established and replicated. Rationally-specified paths accounted for nearly 60 percent of the variance in the kayak criterion and 85 percent of the variance in the plankton criterion. Individual differences in reaction time and incidental learning accounted for over 50 percent of the between-subjects variance. Although specific measures of performance could not be attributed to the influence of separate individual differences, it was clear that quicker and brighter subjects performed better on both tasks. Analysis of the within-subjects variance also yielded coherent

results. Measures of intention most strongly reflected the effect of priority instructions. Both priority and practice positively affected the respective action system indicants for the two tasks. The main effect of practice was most apparent in the motor output measure and the criteria showed both main effects and significant interactions between practice and priority.

Subsequent experiments focussed on the analyses of factors affecting within-subjects variance. Analyses of the underlying task structure and the influences of individual differences were also accomplished but largely corroborated the relationships found in the two initial experiments. The selection of "student or equivalent" subjects, greater amounts of practice and the introduction of verbal side tasks actually enhanced the explanatory power of both analyses. The hierarchic model consistently explained about 65 percent of the overall variance in the performance of the kayak task and 90 percent of the variance in the plankton task. Individual differences in speed and incidental learning accounted for about two-thirds of the observed variance in subjects' game performance averages.

Chapter Six discusses the first attempt to gather data relevant to the proposed information processing model. The game was combined with an auditory-verbal side task involving memory loads of zero, three or five heterophonic consonants. After independently practising the game, ten male and ten female subjects performed each of the nine possible memory load and game priority combinations twice in a counterbalanced design. Increased memory load impaired performance of the uncertain plankton task. In contrast, performance of the complex kayak task actually improved

as memory load increased.

Analysis of post-task questionnaires revealed that there was a marked difference in the average accuracy of subjects' accounts of the two tasks. For the simple task, strategies were entirely consistent with performance. However, for the complex task, subjects' espoused strategies were generally unrelated (and in some instances contrary to) the rules reflected by the regularities in their performance. Subjects' ratings of the game tasks along the dimensions of difficulty, complexity and uncertainty were also collected. Subjects unanimously rated the kayak task as being more difficult than the plankton task. These results suggest the utility of intermediate verbal processing critically depends on the validity of the explicit rules being processed and not necessarily a task's rated difficulty.

The purpose of Experiment Four was to generally replicate the differential interference patterns created by concurrent verbal side tasks but also to gather further data. Two superficially similar but substantively different verbal side tasks were developed. Both involved the articulation of either numbers or directional words in time to a mechanical metronome at a pace of one response every 1.5 seconds. Subjects responded in either a "fixed" sequence or in a consciously generated "random" order. The latter condition was assumed to place heavy demands on general processing resources as well as intermediate verbal mechanisms. After first practising the game alone for 30 minutes, 12 male and 12 female subjects performed all possible combinations of game priorities and verbal side tasks. Fixed-sequence articulatory suppression impaired performance of the simple but uncertain

plankton task but had no effect on the complex kayak task. However, the requirement to produce responses in a random order initially caused decrements in both game tasks. After thirty minutes, randomization continued to significantly impair performance of the plankton task but had no effect on the kayak task. The semantic relevance of the material to be articulated (numbers or directions) had almost no effect on the performance of either task.

These consistent but somewhat counter-intuitive findings might have been mere artifacts of the different response demands of the two game tasks. Alternatively, they might have reflected subjects' mis-allocation of processing resources rather than the effectiveness of the resources. The first argument is that the plankton task typically involved more motor responses (i.e., changes of the whale's direction of travel) and thus interference was caused by response competition rather than interference with intermediate processing. The second argument suggests that because subjects believed the kayak task was more difficult, they increased their efforts when it was combined with the various verbal side tasks. From this view, the lack of interference reflects resource elasticity and the effectiveness of subjects' extra efforts. In contrast, because subjects under-rated the difficulty of the plankton task, they were "caught with their resources down" and performance suffered as a consequence of the additional processing loads.

Chapter Eight presents evidence to rebut both alternative interpretations. Unpaced, fixed-sequence articulatory suppression was used to examine the amount of interference caused by concurrent

peripheral motor activity. Although unpaced, the verbal response rate in this condition was about four times greater than in the previous experiment. To address the issue of intentional mediation, a covert manipulation of resource availability was required. Time, the universal processing resource, was surreptitiously varied by plus or minus 45 msec intervals between game trials. The espoused strategies worksheet and priority rating scales were also administered to replicate the earlier findings.

The results were as follows: 1) unpaced articulatory supppression had nearly no effect on either criteria 2) the effects of time were compatible with the results of the experiments involving verbal side tasks (i.e., more time facilitated performance of the plankton task but not the kayak task) and 3) subject's espoused strategies and subjective evaluations of the prioritiy conditions were nearly identical to those gathered previously. These findings suggested peripheral motor interference was not a sufficient explanation for the interference observed in earlier experiments and that the differential availability of resources, independent of subjects' awareness and thus intentional allocation strategies, was sufficient to induce differential interference in the two game tasks.

Chapter Nine contains a summary of results as well as their synthesis with the initial information processing model. Meta-analyses were accomplished from each of the three perspectives. The similarity of the relationships underlying the games used in the separate experiments was striking, particulary when one takes into account the different subjects and substantively different side tasks as well as numerous minor

modifications to the game itself. Analyses of between-subjects variance largely supported the initial findings: Subjects who were quicker or brighter did better. The meta-analysis of the within-subjects variance was particularly interesting. Criteria for the two tasks showed very different patterns of interference.

Plankton performance was influenced strongly by priority instructions and most improved by shifts from moderate to high levels of priority. Although practice had a positive effect, this was generally mediated by priority. All substantive side tasks (i.e., those assumed to require intermediate cognitive processing) caused significant interference. None of the four conditions which interfered with plankton performance was significantly ameliorated by practice.

Performance of the kayak task was also influenced by priority but greater benefits accompanied shifts from low to moderate levels than shifts to high priority. Practice had almost the same relative effect on performance of the kayak task as on the plankton task, but was less moderated by priority instructions. Only one of the four verbal side tasks interfered significantly with the kayak task but this effect was obliterated by 30 minutes' practice. The effects of the lesser verbal side tasks were generally not significant, but under conditions of low practice and high priority appeared to be facilatatory rather than inhibitory.

In terms of the original model, these results suggest: 1) intermediate verbal processing facilitates performance of the plankton task but, at best, is irrelevant to performance of the kayak task; 2) initially, general attentional processing contributes to both tasks equally and 3) with practice, performance

of the kayak task appeares to depend largely on the relatively-automatic processing provided by implicit knowledge. These results are particularly interesting when the greater complexity and rated difficulty of the kayak task are considered.

Chapter Ten presents the conclusions drawn from these results and discusses the implications in terms of alternative conceptualizations of the human information processing system and the structure of knowledge. It is argued that for simple, uncertain tasks, human information processors behave as single channel, fixed-capacity systems. Their performance of complex but certain tasks, however, requires supplementary explanations. Both the amount of practice and the nature of concurrent processing demands are important determinants of interference with complex task. These results also suggest that implicit and explicit knowledge are, at least to some extent, independent of one another. Areas for further study include: isolating the separate effects of complexity and uncertainty and investigating the application of this approach to questions concerning education and training, personnel selection and task group processes.

The research reported in this thesis reflects an effort to strike the appropriate balance between internal and external validity. Subjects were enthusiastically involved in the performance of the game tasks and most of them enjoyed participating in the experiments. From some perspectives, this necessarily banishes these results from the realm of true psychology. Hopefully, these views are changing.

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A FUNCTIONAL EXAMINATION OF INTERMEDIATE COGNITIVE PROCESSES

CHAPTER ONE

INTRODUCTION

1:1 INTRODUCTION

The goals that motivate this research are not unique. Within the limited context selected, they're the same goals that have motivated much of the research (and controversy) in psychology over the past century. Simply put, this thesis is an attempt to explain human behaviour in a single, moderately-constrained task environment (viz., a computer game).

Even within such a narrow context, explaining behaviour is no mean task. The adequacy of explanation rests on the efficacy of many preliminary functions such as measuring, describing, predicting, controlling and modifying. Measurements must be reliable and objective to be combined effectively to provide valid and sufficient descriptions. Predictive success depends on accurate measurement and adequate description. When the ability to change significantly independent variables is added, to the ability to predict outcomes, modification of performance is possible. But all of these activities together fall short of the final goal of psychology: to provide an explanation. In addition to providing adequate descriptions and demonstrating manipulations bring about predicted results, explanations involve formulating theories that organize known facts into a parsimonious "whole". When the facts are not known or incomplete, explanatory theories provide reasonable guesses (i.e., hypotheses).

Ultimately, scientific inquiry is directed toward the question "Why?". Science is motivated by a desire to know, to understand, and to discover the causes of phenomena. This is true of psychology as well, but its subject matter (the mind and its behavioural manifestations) distinguishes it from other sciences. Although most psychologists share a common commitment to science in general and the scientific method in particular, there is considerable divergence in both the theoretical approaches and procedural techniques employed. It is useful, therefore, to mention several of the individuals and ideas that have influenced the approach taken in this thesis.

Over forty years ago, Kenneth J.W. Craik (1943) combined the doctrine of functionalism with the information processing approach in his classic work, The Nature of Explanation. Although, Craik's functionalism can be traced to William James (1890), he was more directly influenced by the applied and empirical functionalism of his mentor at Cambridge, Frederick Bartlett (1932, 1958). The doctrine of functionalism continues to exert a strong influence on many current psychological theories and concepts. Craik's other major contribution, the information processing approach, has proven equally important. The structure supplied by Craik's formulations has provided a valuable framework as cognitive science has grown and developed over the last few decades.

Craik's doctrine of functionalism is essentially illustrated by the following recently-presented example (Johnson-Laird, 1983). A computer program that simulates the action of a wave breaking on the shore differs from a real wave in many respects. It would, however, be inappropriate to criticize it for not being wet. The

utility of examining processes, even though their underlying structures are not fully understood, has often been demonstrated. Just as computer programming may be productively studied without mastery of machine code and electronics, the study of the mind can be pursued in at least partial independence of the neurophysiology of the brain.

The biological structures of the brain are not unimportant, but their greatest significance lies in the constraints they place on mental functions. One is likely to glean a great deal more useful information from examining how a computerized chess game performs than by immediately tearing it apart and attempting to analyse the electrical characteristics of its internal components. The weakness inherent in exclusively "bottom-up" approaches is that one simply does not know what "questions" to ask nor how to interpret and integrate the "answers" one discovers.

In presenting his hypotheses concerning the nature of thought, Craik (1943) suggests prediction is the pre-eminent goal of mental function. This goal, in turn, depends on three subordinate but essential and interdependent functional components:

> 1) translation of external processes into words, numbers, and other symbols, 2) arrival at other symbols by a process of "reasoning" deduction, inference, etc. and 3) retranslation of these symbols into external processes or at least, a recognition of the correspondence between these symbols and external events. (Craik, 1943, p. 50)

Craik thus provides a prototypical, three-stage, "functional", information processing model. He was not vaguely hypothesizing about "structures in the head" but neither did he provide specific constraints on exactly how these processes might be performed (i.e., sequentially or in parallel or by some

combination of the two). He was, however, very clear about the function of these components. These processes are the means by which humans develop internal models which are capable of producing results similar to, but independent of ongoing external events. By internalizing the "relation-structure" of the processes manifested by events, these internal "mental models" enable humans to make useful albeit imperfect predictions concerning themselves, their environments and interactions between the two (viz., their own performance). The fundamental importance of prediction lies in its recursive enhancement of the component functions which created the model.

1:2 THIS THESIS

The present thesis may be defined in terms of the foregoing concepts. It will focus on the second of Craik's three component functions - that comprising the processes which lie between the acquisition of internal representations and the initiation of responses to the information contained in those representations. While it is intuitively appealing to label these processes "Central Decision Making", such a label implies several dubious assumptions. A brief examination of the three seemingly innocuous words which make up this vernacular millstone illustrate this point.

Because "central" is a spatial term it invites confusion between structural and functional approaches. It is entirely possible that some temporally or physiologically central processes are functionally quite peripheral and vice versa. "Central" also strongly, and perhaps inappropriately, asserts the relative significance of intervening processes.

Problems also inhere in the term "decision" and its attendant characteristics of finality, unity, and completeness. Ongoing and individually incomplete mini-states seem a more useful metric for investigating intermediate cognitive processes. The term "decision" reflects a post-hoc verbal reconstruction of what must have taken place. Such a reconstruction might be accomplished by compressing many psychologically significant increments into a somewhat artificially unified "whole". (More will be revealed concerning the curious role of verbalization shortly.)

One can even find fault with the final gerund, "making". Intermediate cognitive functions necessarily involve both excitatory and inhibitory processes. Logically, if a system is to maintain homeostasis the effects of these two processes must be approximately equal. "Make" is a term biased in favour of the former (excitatory or active) processes and against the latter (inhibitory or passive) ones. This may be characteristic of intermediate processes, but it would be much more appropriately established by presenting evidence and argument than by obliquely asserting its validity by selecting a prejudicial label.

There is yet another problem with the "Central Decision Making" label. A major obstacle to the scientific study of the mind was the problem of the infinite regress presented by the Scottish philosopher, David Hume in the eighteenth century. Hume argued that hypothesizing about pictures or anything else in the head begged the question of who or what would look at, feel, or experience these representations. The creation of the little man inside the head, known fondly to philosophers as the "homunculus", suggested an endless series of such homunculi, nested inside each

others' heads like Russian egg dolls. This dilemma proved insurmountable for over a century.

Eventually, an approach adopted by the early structuralists provided a means of overcoming the infinite regress. Their solution was to decompose consciousness into separate components. As the contemporary philosopher, Daniel Dennett (1983) points out, if one hypothesizes homuncular committees, hierarchically arranged, with each homunculus knowing more and more about less and less, the regress is no longer infinite. The bounding condition is the homunculus who "knows" almost everything about practically nothing. (This is not an altogether inaccurate functional description of the fundamental physiological building block of the brain: the single neuron.)

However, in addition to circumventing the infinite regress, the structuralists injected psychology with difficulties so virulent, they have resurfaced time and again throughout the last century. The seemingly innocuous practice of relying on subjects' verbal reports of experiences has proven extremely problematic. Although this method is both logically and intuitively appealing ("the fallacy of the horse's mouth"), it is empirically disastrous. It is not verbal reports themselves that cause the trouble. However, the attendant assumption that subjects' verbalizations accurately reflect significant cognitive processes transforms a merely weak procedure into a serious threat to experimental validity.

As it turns out, the member of the homuncular committee responsible for verbal reports is not the omniscient, omnipotent cognitive controller the structuralists assumed. Dennett (1983)

provides a more colourful and accurate description of the homunculus serving as "director of public relations" (i.e., the one with direct access to verbal mechanisms):

> (He is)... the agent in the press office who has only a limited and often fallacious idea about what's really going on in the system. He's the one whose job it is to present a good face to the world, to issue press releases and generally try and tell everybody on the outside what is going on. He can be wrong, he can be massively misinformed; he can be massively ignorant. (p. 79)

Over the last century most psychologists have realized the fallacy of the structuralists' assumption that everything could be made accessible to verbal report. Unfortunately, many still assume, often implicitly, that verbal reports are a fully-contained subset of cognitive activities. As the early structuralists demonstated, introspection is an intuitively seductive way of polluting good psychology with bad philosophy. Craik (1943) was referring to the fundamental flaw in this approach when he noted:

> It (introspection) does not take into account that in any well-made machine, one is ignorant of the working parts... the better they work, the less we are conscious of them... Thus it is unlikely introspection will reveal those intermediate processes which are most important. (p. 83)

This thesis contains an examination of functional aspects of intermediate cognitive processes. The unique function of these processes is to combine information from internal representations of current external events with existing knowledge to determine intended responses.

1:3 A GENERAL APPROACH

Such a broad topic necessarily involves difficulties in the initial stages of inquiry. However, approaching problems at this

global level has considerable "down-stream" advantages. There remains, however, the immediate problem of finding a place to begin. Fodor (1983a, 1983b), for example, noting that the central system is inherently "isotropic" (i.e. referring to the fact that relevant facts may be drawn from anywhere previously stored thus implying, ipso facto, "unencapsulation") and "Quinean" (i.e. referring to the characteristic that the degree of confirmation assigned to a given proposition is sensitive to the properties of the system as a whole), argues that peripheral input modules pose an absolute limit to epistemological advances. This is stated rather presumptuously in "Fodor's First Law of the Non-Existence of Cognitive Science": "the more global a cognitive process, the less anybody understands it." He maintains, somewhat pessimistically, that central systems are simply beyond the purview of scientific inquiry.

Jenkins (1974) is in agreement with Fodor concerning the inadequacy of traditional empirical methods. However, he attributes this difficulty to the influence of "Associationism," a blend of the worst aspects of structuralism and behaviourism, which involves:

> a belief in basic units... relations between units... that more complex behaviors are the same 'kind' as simple ones... that explanation consists of explication of mechanisms... (and finally) behavior is automatic... This view is so pervasive ...it is almost coextensive with being an experimentalist. (Jenkins, 1974, p. 786)

Jenkins offers as an alternative: the Contextualist Formulation. Contextualism is one aspect of the broader philosophical position espoused by John Dewey: Pragmatism (which is, again, related to the functionalism of William James and Kenneth J.W. Craik).

Contextualism rests on a different set of assumptions: experience consists of events; events have a quality (or meaning) as a whole; this quality may be defined in terms of interactions between the organism and the immediate physical environment; these relations are defined as "texture" and are composed of temporal "strands" lying in situational "contexts."

Contextualism challenges assumptions underlying the traditional empirical strategies of "simplifying and observing" espoused in contemporary research texts (e.g., Moore, 1983; Mook, 1982). That which is simplified (e.g., the "simplified fish" in a classic neurophysiological study conducted by Von Holst were actually "dead" fish (Gallistel, 1980)) out of empirical necessity may be transformed in such a way that experimental observations may no longer provide valid answers to the empirical questions which require the initial simplification. Contextualism maintains that there is unlikely to be a single unified account of anything; there are too many contingencies.

Kosslyn (1980) makes a similar point in introducing his inquiry into mental imagery. Like both Fodor and Jenkins, he maintains that pure empiricism cannot resolve the problem of sustaining multiple and sometimes incompatible assumptions. Like Jenkins and unlike Fodor, Kosslyn seeks an alternative to outright surrender. He develops a heuristic based on Newell's (1973) "bootstrapping technique." The research strategy adopted for this thesis incorporates several aspects of these approaches.

Three steps are involved: 1) creating a general conceptual model capable of integrating existing "phenomena", 2) using this model to direct the search for additional "system critical"

information, and 3) using the new data to gradually "tighten" the original model. Premature evaluation is a particularly pernicious threat to the initiation of scientific inquiry. By employing general criteria such as "elegance" (which Newell (1973) defines as the state of being "natural, straight-forward and parsimonious") to develop the initial model, reference to purely explicit criteria is held in abeyance. This is not really too unlike what successful scientists have been doing all along. As Alan Turing (1950) suggested:

> The popular view that scientists proceed inexorably from well-established fact to well-established fact, never being influenced by any unproven conjecture is quite mistaken. Provided it is clear which are proven facts and which are conjectures, no harm can result. Conjectures are of great importance since they suggest useful lines of inquiry. (p. 57)

After the initial model, a sort of meta-conjecture, is developed, it serves as a frame for the research process. This allows the systematic reintroduction of explicit criteria and traditional empirical techniques without compromising those aspects of the cognitive process which made it psychologically interesting in the first place. The meta-model serves a different function than theoretical models in traditional approaches. Because it represents a synthesis of existing evidence, its disconfirmation implies the rejection of this evidence. This type of model is generally not disproved but replaced by a theory which is either more parsimonious or is able to account for a broader range of evidence with less elaboration. Within the meta-model, however, alternative theoretical formulations vie for ascendancy and the right to incorporation in the traditional manner (i.e., by trying to disprove unequivocally one another).

Before developing the meta-model, one issue deserves special comment. "Ecological validity" is a phrase that has become ubiquitous in the current academic literature (non-academics probably have trouble imaging any other kind of validity). It is unfortunate that a term used so freely and frequently is so rarely defined objectively. In fact, if one looks closely at the experimental procedures and designs employed in its name, apart from the obligatory homage paid to it, the impression that ecological validity involves only superficial concessions to extra-academic reality is unavoidable. Experimental tasks, procedures and equipment are often simply "touched up" so they appear more similar to everyday tasks and thus more "valid.".

However, real ecological validity involves more than face validity. It involves making a series of difficult choices to achieve the optimal balance between internal and external validity. The internal experimental design, measures, and controls must be sufficient to ensure objective, replicable and statistically significant answers to researchers' questions. On the other hand, if these internal factors are overly robust, they pose the danger of metamorphosing the processes being examined thus confounding and invalidating the results they were employed to protect.

Three specific aspects of the issue of ecological validity are critical: 1) the semantic and affective contexts within which experiments take place, 2) the adequacy of description of the substantive characteristics of the experimental tasks themselves, and 3) the metric efficacy of the dependent variables to reflect important aspects of performance. These issues will be discussed in greater detail in the next two chapters.

The first task is to develop the meta-model. Because intermediate cognitive processes are involved in virtually every aspect of psychology (particularly human experimental psychology) more than a cursory literature review is not possible. Issues necessary for the development of the proposed model have been selected and will be presented in an admittedly abbreviated manner. However, by focussing on evidence and argument relevant to certain key distinctions within the information processing system, the outlines of a meta-model emerge.

The first type of distinction deals with differentiating intermediate cognitive processes from other factors which influence performance. The acquisition of representations (i.e., perception) and the execution of intentions (i.e., motor processes), are two extremely important factors which are, at least directly, beyond the scope of the discussion and experimental work which follows.

It is important to propose distinctions within intermediate cognitive processes, as well as to differentiate these processes from "peripheral" activities. The first such distinction concerns different types or modes of processing. Many contemporary psychological theorists present findings and propose models which include two or more separate modes of intermediate information processing. Although most of these formulations contain distinctive features which impede easy comparison or direct translation into common frameworks, there seems to be considerable overlap. A general distinction between two processing modes ("automatic" and "controlled") which rely on different cognitive components (i.e., knowledge and attentional mechanisms respectively) will be presented.

Within each of these general components, other potential distinctions will be considered. Knowledge (or alternatively: "skill") is most heavily involved in "automatic" processes and might be differentiated along a number of dimensions (e.g., innate-acquired, declarative-procedural, or implicit-explicit). Likewise, the attentional mechanisms of "controlled" processing may be differentiated. Much of the controversy concerning central versus multiple resource theories has dealt with the nature and extent to which intermediate processing mechanisms should be differentiated. Although the resolution of this controversy is beyond the scope of a mere thesis, several possible distinctions will be discussed and experimentally investigated.

1:4 DIFFERENTIATING INTERMEDIATE FROM PERIPHERAL PROCESSES

The tradition of decomposing task performance into what are assumed to be independent and sequential stages is nearly as old as psychology itself. Donders (1969) assumed the duration of a processing operation could be measured by comparing the time taken to complete a task in which the operation was performed with the time taken to complete a version of the task in which the operation was not performed. Donders relied on this "subtractive" method to suggest three sequential stages similar to those later employed by Craik (1943), (i.e., representation acquisition, intermediate transformations, and execution). A modern version of this type of approach is S. Sternberg's (1969, 1975) additive-factor method. Again the assumption is made that task processing is made up of a series of stages and that each stage receives an informational input from the preceding stage, transforms it (independently of the

duration of any previous processing), and passes it on to the next stage. Temporal interactions between experimental manipulations is taken as evidence that these manipulations are effecting the same stage, but additivity suggests the manipulations effect different stages. R. Sternberg (1977, 1985) proposes elaborate procedures and rigorous analyses (which rely on similar "sequential" and "independent" assumptions) to identify the processing stages in subjects' solutions to analogy problems.

Despite the apparent utility of conceptualizing and applying "stage" discriminations, the tendency of this approach to converge upon its own assumptions is worrying.

> This method meets considerable difficulty of postulating a priori the stages involved in different tasks, without any guarantee or check about the validity of the assumptions. In fact the subtractive method has failed on many occasions... The building blocks may clearly not behave according to our intuitions about their nature and accompanying task efforts... It is easy to construct a diagram but hard to carry out critical tests. (Gopher & Sanders, 1984, pp. 234-235)

In fact, the two assumptions (i.e., independence and strict seriality) on which "stage" methodologies critically depend are vulnerable to a number of criticisms. The well-established influence of spatial correspondence between stimuli and responses (Fitts & Seeger, 1953) suggests dependencies that obtain through all hypothesized processing stages. Differences at one conceptual stage affect both preceding and subsequent processes. Similarly, there is a great deal of evidence to suggest the modality of stimulus presentation can have effects which endure well beyond the acquisition of representations (McLeod, 1977; Wickens, Sandry and Vidulich, 1983).

Asymmetrical interference in dual task performance provides

several examples. Allport, Antonis & Reynolds (1972) found that although subjects could type or sight-read and play piano music with minimal interference while "shadowing" an auditory message, combining typing to dictation with vocal reading of visual material proved to be almost impossible. Likewise, Shaffer (1975) found that although his subject (a skilled typist) could type visually-presented text at high speed while simultaneously shadowing an auditory message or reciting, she encountered great difficulty in combining auditory typing with shadowing, reading aloud or reciting.

Along this same line, McLeod and Posner (1985) review considerable evidence and conclude that the mapping between auditory inputs and verbal outputs is so strong it constitutes a "priveleged" pathway within the information processing system. In presenting his "Theory of Multiple Intelligence", Gardner (1983) suggests that several "intelligences" or processing modules have particularly strong functional as well as neural connections with specific input and output modalities. The language module is closely related to the auditory and oral systems, while other intelligences such as spatial and body-kinesthetic ones are more closely tied to visual and motor systems.

Evidence disconfirming the assumption of strict seriality of the three basic processing stages is presented by Eriksen and Shultz (1979) in their argument for a "continuous flow" processing conceptualization. By showing that visual noise affects both speed and accuracy in visual search, they suggest information accumulates gradually in the visual system directly and concurrently priming alternative responses. In place of a discrete intervening stage,

Eriksen and Shultz (1979) maintain that decisional activities are more accurately represented as largely inhibitory moderating influences on discrete response tendencies.

For a variety of reasons, research based on the assumptions of sequential and independent stages has vaned (Hunt's (1978) experiments with verbal ability provide a curious exception). Some authors have abandoned "stages" altogether in favour of completely (Allport, 1980) or primarily (Gardner, 1983) modular systems. Others have relied on stages to conceptually partition the information processing system. For example, Fodor (1983a) relies on a theoretical distinction between input modules and the "central system" to establish the "absolute" limits of science. In contrast, Wickens (1980) combines encoding and central processing stages to yield a dichotomous temporal partition of early and late stages for his "multiple resource" formulation. After comparing the nature, assumptions and "predictive potential" of linear stage and capacity allocation frameworks, Gopher and Sanders (1984) conclude:"to a considerable extent they are concerned with different questions and, therefore, should be regarded as largely complementary" (p. 253). Fodor (1983a) suggests a similarly orthogonal relationship by contrasting Gall's (and his own) interest in "vertical" faculties with more traditional "horizontal" partionings such as those reflected by perception, memory, and motor skills.

In presenting his version of a central capacity resource theory, Kahneman (1973) is careful to distinguish his claims concerning central capacity from interference caused by competition for "satellite" structures (i.e., peripheral mechanisms). The

model and experiments to be presented in this thesis are concerned with intermediate cognitive components and processes (as was Kahneman's theory). Although the influences of perceptual and motor output systems are not extricable, they must be controlled. Despite the evidence that stages represent dimensions which are largely orthogonal to those aspects of the system which receive the preponderance of both experimental and neurophysiological support, they remain theoretically and pragmatically useful. As Eysenck (1984) points out:

> any adequate analysis of effects of similarity on dual task performance must recognise that there are at least three different kinds of similarity that must be distinguished: similarity of stimuli; similarity of internal processing operations; and similarity of responses. (p. 60)

Stages are more than a convenient fiction; they provide initial procedural distinctions. These distinctions are particularly relevant because the experiments which follow employ measures of dual task performance to show differential patterns of interference.

1:5 DIFFERENTIATION WITHIN INTERMEDIATE PROCESSES

The first distinction to be made is that concerning alternative "modes" of information processing. Although it is nearly impossible to find a contemporary conceptualization of the human information processing system which does not include alternative pathways, there is significant variation in the number, nature and names of distinctions proposed. However, if one considers formulations from many separate domains which suggest single (and presumably the most important) distinctions between alternative modes, considerable overlap becomes apparent.

Many of the current proliferation of information processing formulations espousing alternative pathways have developed as reactions to early "pipeline" models. These models (e.g., Broadbent, 1958; Waugh and Norman, 1965; or Moray, 1967, 1969) all maintained that fixed and generally passive mechanisms determined the "flow" of information through a system of strictly-limited capacity. However, the flexibility and resourcefulness human subjects frequently demonstrate (often to experimenters' chagrin), suggested pathways were less "fixed" and capacity less "limited" than these models implied.

Although Broadbent's (1958) initial model was predicated on the assumption of the need to "filter" incoming information to provide "overload" protection for a subsequent limited-capacity general processor, the control process was not elaborated. Careful consideration of the issue of control was, however, incorporated in Broadbent's (1971) later models. Two distinctly different control systems (a relatively passive lower mechanism and an active, cognitive, upper mechanism) were thoroughly discussed and empirically supported.

Shiffrin and Schneider (1977) distinguished two separate modes of processing in their extensive (and intensive) experiments with visual search tasks. They found that when targets and distractors remained the same for thousands of trials, subjects' response latencies became relatively insensitive to the number of potential targets or presented distractors. Shiffrin and Schneider (1977) also found that once this apparently "automatic" processing capacity was developed and target and distractor groups were then reversed, subjects required nearly a thousand additional trials to

escape the interference caused by their previous learning. These authors concluded that extensive practice enables subjects to develop the capacity to process information "automatically". Compared to controlled, conscious, and sequential processing, automatic processing was characterized as being very quick, passive, and independent of attentional mechanisms.

Earlier, Posner (1973) had employed a similar distinction to differentiate "effortful" and "effortless" retrieval of information from memory. Subsequently, Posner and Snyder (1975) had suggested on evidence from matching and classification paradigms that when stimuli were expected, conscious attention speeded responses but when unexpected stimuli arrived, conscious attention slowed responses. Switching attention from the "expected event" to the "actual event" apparently required time. Posner and Snyder (1975) suggested that another process, "automatic activation" speeded decisions when priming words were semantically related to the target words but did not create temporal costs if target words were semantically unrelated. The relative influence of these two processes is very sensitive to the time interval between the prime and the target word; automatic facilitation occurs almost immediately but the costs or benefits attributable to conscious expectancies take time to develop.

Neely (1977) employed a lexical decision task and manipulated conscious expectancies and semantic relationships separately at different prime-to-target time intervals to provide supportive evidence. Consistent with Posner and Snyder's (1975) predictions, decision time increased as the interval between prime and target increased if an unexpected target appeared (and decreased as the

interval increased if the target was expected). At the shortest interval (250 msec), semantically related primes facilitated responses but this effect decreased as the interval increased.

Broadbent (1977) employed a similar distinction to separate early, passive, and global "preattentive" processes from subsequent active and more detailed attentional processes. He also speculated that these two types of processes served different functions: preattentive processes "suggest" likely interpretations or appropriate responses and active attentional processing "verifies" these suggestions and initiate responses. Becker (1976) had previously introduced a very similar verification notion to describe processes involved in visual word recognition. Navon (1977) also presents evidence for the "precedence" for the processing of global features.

In his study contrasting cognitive and affective judgements Zajonc (1980) relies on a distinction between processing modes to support his view that "preferences" and "inferences" can be independent. He contrasts quick, early, gross and vague affective processing with slow, later, verbal and concise cognitive processing. An experiment by Keenan and Bailett (1979) illustrates this distinction: their subjects were asked to judge whether a number of adjectives described themselves, their best friend, a parent, another friend, a teacher, a favourite television character or Jimmy Carter. Subjects were subsequently given a recognition memory task in which the original adjectives were combined with an equal number of similar but novel adjectives.

Keenan and Bailett found the self-referent criteria resulted in the best recognition performance (over 90 percent correct) while

reference to Jimmy Carter produced less than 65 percent correct (a score of 50 percent would be expected by chance). The other scores directly reflected the social significance of the criterion person. However, contrary to the predictions of many information processing models, response times in the original judgement task decreased significantly as the social significance of the criteria person (and subsequent recall accuracy) increased. This is a direct contradiction of the earlier belief that memory was positively and directly related to the time spent reheasing or elaborating material (e.g., Atkinson and Shiffrin, 1968; Waugh and Norman, 1965) and is also not explicable in terms of levels of processing models (e.g., Craik and Lockhart, 1972; Craik and Tulving, 1975).

A similarly counter-intuitive result from a novel paradigm is presented by Presson and Hazelrigg (1984). These authors first "taught" subjects an actual physical path in one of three ways: 1) by showing them a map of the path, 2) by physically leading them blindfolded along the path or 3) by showing them the entire path from a single elevated vantage point. During the next part of the experiment, all subjects were blindfolded and led along the path and at predetermined points stopped and instructed to point to another prominent point along the path. On half these trials, subjects were turned 180 degrees (i.e., counter-aligned) before pointing. Pointing accuracy was the sole criterion.

Presson and Hazelrigg report that although the map group performed much better than the other two groups (i.e., walk and look) when "aligned" with the path, they performed worse than either group when "counter-aligned". In fact, counter-alignment increased the map group's average error from 20 to over 65 degrees,

but only increased average errors by 5 degrees for the other two groups. These results are consistent with Presson and Hazelrigg's distinction between primary (direct) and secondary (symbolic) learning. "Firsthand" experience whether tactile, kinesthetic or visual results in primary learning, whereas the study of written text, maps or other symbols results in secondary learning. Learning of the latter type yields "figural representations" which can be applied with great precision but are susceptible to interference and confusion. In contrast, direct primary "literal" learning is less precise but more robust.

This result reflects a distinction similar to the one that has been repeatedly demonstrated by the work of Reber and others (e.g., Reber, 1976; Reber & Lewis, 1977; Allen & Reber, 1980; and Reber & Kassin, 1980). In a prototypical experiment, standard Markovian grammars are used to generate 50 letter strings of 3 to 8 consonants. Groups of subjects advised to try explicitly to discover the underlying grammatical rules, typically do much worse on both concurrent tasks and subsequent recognition and generational tasks. Reber suggests that a "nonconscious abstraction system" operates when the stimulus environment exhibits complex structure and subjects do not explicitly attempt to "break the code". This system operates "naturally and simply" in contrast to the laboured and conscious hypothesis-testing of explicit strategies. Reber and Kassin (1980) conclude:

> Complex structures such as those underlying language, socialization, perception and sophisticated games are acquired implicitly and unconsciously. (p. 495)

Reber's formulation and experimental procedures imply that the two processing modes are mutually exclusive, and that verbal

instructions can predispose subjects to operate in one or the other. Although Sanford and Garrod (1981) suggest a similar procedural distinction, they contend the alternative processes occur in a closer and more complementary relationship. They suggest the "primary processes" for understanding written language are performed rapidly and automatically by an interpretive system based on subjects' general knowledge of situations, events, objects and characters. In contrast, "secondary processes" require the "explicit focus" of limited attentional mechanisms and employment of "representational tokens" or symbols. These two processes normally work in concert; only when a text is unclear or incongruent with the mental model being developed, primary processes are augmented by more conscious and effortful secondary processes.

Similar distinctions have been propounded in the popular press. Tennis professional, Tim Gallwey's (1974) best seller, The Inner Game of Tennis, is clearly based on principles related to those suggested by Reber's empirical studies. Gallwey's "inner-game approach" includes the idea that the mind contains a verbal "Self 1" and a separate non-conscious "Self 2" which actually plays the game. The goal of the inner game is to get Self 1 to stand aside and "allow" Self 2 to perform.

Verbal instructions are employed only when absolutely necessary, and never in relation to actual physical movements. Gallwey suggests overt distraction to forcefully disengage the verbal self during tennis practice: while the ball is being volleyed, the student says aloud "Bounce!" or "Hit!" each time one of these events occurs. This verbal task keeps Self 1 (the verbal

mechanism) occupied and thus ensures body and racket movement are under the control of Self 2. (This technique is predicated on the assumption that Self 1 has a strictly limited processing capacity which is easily saturated.)

Artist, Betty Edwards' (1979) best-seller, Drawing with the Right Side of Your Brain, is based on similar principles and introduces a number of exercises, through which students might escape the control of their normally-dominant, highly-verbal left hemispheres. Her contention is that drawing is fundamentally a complex, abstract, spatial, perceptual task which can best be performed passively and subconsciously by the right hemisphere.

Likewise, inventor and entrepeneur, Thomas Blakeslee (1980) endorses a two-process perspective his book, The Right Brain; A New Understanding of the Unconscious Mind and Its Creative Powers. Additionally, contemporary work in the emerging field of sports psychology is concerned with performance under non-verbal, semi-conscious control conditions referred to as "flow states" (Dorfman, 1985). Although the academic community continues to display scepticism, the notion that verbal resources can be negatively related to both performance and skill acquisition has been lucratively applied to a wide variety of "everyday" skills.

Dual process formulations also receive clinical and neurological support. Callaway and Naghdi (1982) combined reaction time tasks and physiological measures such as average evoked potential (AEP) to support their information processing explanation of schizophrenia. Two types of processes are discriminated: one controlled, sequential, conscious, top-down and of limited capacity;and the other automatic, parallel, unconscious, bottom-up

and of "almost limitless" capacity. The evidence Callaway and Naghdi (1982) present suggests that although schizophrenics show impairment of active, conscious processing, their automatic, unconscious processes are often normal or even supernormal.

The neurological evidence for distinguishing separate processing systems is also considerable. The following comment and illustration by Geshwind (1983) is representative:

> Consider some situations in which you move your arm. You move it throwing a ball, and in yawning. Most people assume that in every case the movement of the arm is controlled by the same system. In fact, we know the movement of the arm can be controlled from many different locations and that after damage to one part of the brain, some types of movement of the arm may be lost while others are preserved. Take for example the patient who has had a stroke, which led to paralysis of the right arm. The patient finds it relatively easy to bring the arm in to the side with elbow and wrist bent and with the fingers clenched. By contrast, it is very difficult, often impossible, for the patient to hold the arm fully outstretched to the side. Yet the patient may yawn, and, to his own astonishment, the 'paralysed' arm may rise and produce exactly the 'impossible movement'. (p. 126)

Neumann (1984) provides an extensive review and useful synthesis of many of the findings relating to "automatic" processing in a variety of human experimental tasks. He points out that automaticity, currently, is seen to involve three aspects: 1) a mode of operation (i.e., it operates without interference or capacity limitations), 2) a mode of control (i.e., it is controlled by stimulus characteristics rather than subjects' intentions), and 3) a mode of representation (i.e., it does not necessarily give rise to conscious awareness). Neumann suggests automatic processes are not actually free from suffering or producing interference, employing arguments similar to those presented by Broadbent (1982).

Neumann (1984) also argues that automatic processes are not

independent of individuals' current intentions. He stipulates, however, that some processes dependent on intention are not explicitly intended and that other dependent processes may not even conform to intention. He suggests the "levels of control" formulation of automaticity first offered by Wundt (1903) (and retained in skills and motor performance research) best accommodates the empirical evidence. Neumann (1984) suggests relative automaticity is determined by the respective contributions of two alternative modes of parametric specification:

> Automatization is the acquisition of skills that enable actions or parts of actions to be controlled at a level not associated with conscious awareness... A process is automatic, if all its parameters are specified by a skill (a procedure stored in long term memory) in conjunction with environmental information. If these two sources of constraint cannot specify all parameters, further constraints must be provided by attentional mechanisms. (p. 293)

Neumann's (1984) conceptualization reflects an important distinction between two functionally different aspects (or components) of the human information processing system. Although these two components are theoretically distinguishable, the performance of most tasks requires their integration rather than exclusive reliance on one or the other. As Neumann (1984) suggests, tasks can be represented as specification requirements for a number of parameters.

Extending Neumann's position further, it can be argued that the extent to which a task's parameters are specified by "skills," knowledge, or other internally-stored representations of the task's relation structure, the task will be performed with even greater automaticity. These are the primary methods of parameter specification (i.e., information processing); they are rapid and

"preattentive". To the extent the task requires further constraint (i.e., necessary parameters are left "unspecified" because of the lack of either stored information or procedures), limited-capacity attentional mechanisms are required and the automaticity of performance decreases.

Other characteristics help to distinquish conceptually between the two types of components suggested. Skills are relatively enduring representations - the stored "context,", values, and programs of the processing system. In contrast, attentional mechanisms are agnostic processing entities, the conceptual loci of "conscious activities". The proposed distinction lies between the two fundamental parts of representational systems identified by Rumelhart and Norman (1983): stored data structures and the processes which operate upon those structures. What remains is to examine each of these components (i.e, skills and attentional mechanisms) to discern what further differentiatiation is possible and necessary.

1:6 SKILLS AND THE STRUCTURE OF KNOWLEDGE

Skills are the embodiment of knowledge concerning the structural relations which obtain within and between the subject and the outside world. Two questions are of concern: 1) the genesis of these informational structures and 2) their representational form. These will be dealt with sequentially.

Bryan and Harter's (1897) study of telegraphers' performance and Woodworth's (1899) analyses of the characteristics of repetitive movements are amongst the earliest studies of human skills. In both studies, practice resulted in relatively

continuous and logarithmically linear improvement in performance.

Rabbitt (1981) offers an explication of the process by which practice improves performance. A consistent characteristic of the effect of practice on performance is a relatively large decrease in the amount of variation in response latencies accompanied by a smaller decrease in the average value of those latencies. Rabbitt (1981) maintains that subjects gradually gain operational knowledge of their own speed-error-tradeoff-functions. They then employ this knowledge subconsciously to adjust internal completion times of all necessary subprocesses to meet overall, conscious speed criteria. Subjects respond incrementally more quickly until an error occurs, then immediately tighten response criteria to ensure succeeding performance is more accurate. This post-error latency increment is inversely proportional to subjects' knowledge of task requirements and their own capabilities. Well-practised subjects make relatively small adjustments, but novices often quite grossly overcompensate for small errors by making very large adjustments.

A number of studies cited earlier show the positive effects of practice. Experiments by Allport, Antonis and Reynolds (1972) and Shaffer (1975) provide examples of well-practised skills being relatively insensitive to interference effects when combined with certain other side tasks. Shiffrin and Schneider (1977) observed the effects of practice directly and explained the automaticity (i.e., the difficulty insensitivity) which developed with "consistent-mapping" by hypothesizing "direct" linkages between stimuli and responses. Such enduring "links" represent a form of "knowledge" acquired through practice.

Perhaps the most frequently cited experiments of the

"practice-makes-perfect" genre are those conducted by Spelke, Hirst, and Neisser (1976) in which two college students received training on a variety of tasks for five hours each week over a period of four months. Their initial tasks were reading short stories for comprehension and writing down dictated words. Initially subjects' reading speed and recording accuracy were relatively poor when the tasks were combined. However, after six weeks practice, the subjects were able to read as rapidly and with as much comprehension when taking dictation as when reading alone.

Closer examination, however, revealed subjects could only recall 35 of the thousands of words they had written. Even when 20 successive words formed a sentence or represented a single semantic category, subjects were apparently oblivious to these features. However, with a little more training and a lot more practice, both subjects learned to write categorical labels for aurally-presented words while maintaining normal reading speed and comprehension. These studies suggest that with sufficient practice, even relatively complex tasks can be performed concurrently without apparent disruption.

Internal representations of the outside world are necessarily constructed from interactions between the physical environment and input systems. Although the adaptive significance of a perceptual system with minimal distortion is difficult to dispute, there are many examples where perceptions clearly exceed the objective physical evidence (Gregory, 1972; Rock, 1984). People "see" bands of colour in a rainbow although the rainbow contains only a linear and continual gradation of refracted wavelengths. These discontinuities are a perceptual fiction. However, because such

fictions are not harmful, they are not "selected out" by evolutionary forces (Gould, 1984).

Spatial and modality compatibility effects are also examples of innate, hard-wired, neurologically-based characteristics which affect the nature of internal representations and contingent behaviours. Because these processing characteristics interact with incoming information, they become part of the resultant internal knowledge structures. The tradeoffs which occur between practice and compatibility reflect the closeness of the relationship. Wickens (1984a) reviews the supportive evidence:

> Leonard (1959) found that no practice was needed to obtain a flat slope with the highly compatible mapping of finger presses to tactile stimulation. Davis, Moray, and Treisman (1961) required a few hundred trials to obtain a flat slope with the slightly lower compatibility task of naming a heard word. Mowbray and Rhoades (1959) examined a mapping of slightly lower (but still high) compatibility. Subjects depressed keys adjacent to lights. For these unusually stoic subjects, 42,000 trials were required to produce a flat slope. (p. 355)

Although compensatory tradeoffs are possible, slight increases in compatibility can obviate tremendous amounts of practice. Skills (stored representations of relation-structures) are influenced by both the innate characteristics of the information processing system and the number and type of interactions between the system and the outside world (viz., experience). Another question concerns the nature of the representation itself.

Tulving (1972) distinguishes between representations of specific events (episodic memory) and a body of accumulated information referred to as "semantic memory". In contrast with episodic memory (which most psychological experiments involve), Tulving suggests that semantic memory is the more crucial to

performing everyday tasks:

> It is a mental thesaurus, the organized knowledge about words and other verbal symbols, their meanings and referents, relations among them, and about rules, formulas and algorithms for the manipulation of these symbols, concepts and relations. Semantic memory does not register perceptible properties of inputs, but rather cognitive referents of input signals. (p. 386)

But as Eysenck (1984) points out, there is "no precise dividing line" between episodic and semantic memory and although the distinction may have "heuristic value, it has a somewhat dubious theoretical status." (p. 306)

This reservation notwithstanding, within semantic memory, a number of additional distinctions have been proposed. Rumelhart and Norman (1983) discuss "three major controversies" concerning representational formats: 1) the propositional-analogical controversy, 2) the continuous-discrete controversy, and 3) the declarative-procedural controversy. After suggesting these distinctions are somewhat arbitrary, post hoc attempts to impose simple dimensions on complex, labile and multivariate structures, Rumelhart and Norman espouse synthesizing these dimensions into a single global concept or "virtual knowledge". Their arguments follow Turing's (1950) classic defence of functionalism, that because discrete, propositional, digital computers can "simulate" the output of continuous or analogous systems, the two types of systems are empirically equivalent. Because functional equivalence is tantamount to theoretical redundancy; these distinctions will be omitted from the model.

Another distinction, that between "implicit" and "explicit" knowledge, however, warrants careful consideration. The term "explicit" could be limited to that which is definite, expressed in

minute detail, and directly and clearly stated. There is, however, an advantage to expanding the definition to include knowledge which subjects can only talk about in general, inexact terms. This broader definition avoids endless semantic (in the pejorative sense) quibbles concerning the definitions of "definite", "detailed", "clear", and "direct", but retains the fundamentally most important distinction between what people say and do.

The distinction between explicit and implicit knowledge is not the same as the declarative-procedural distinction (contrary to the assumption of a rather close relationship by Cohen and Squire (1980) or Rumelhart and Norman (1983) and others). The following experiment by Pew (1974) clearly demonstrates both the difference between implicit and explicit knowledge as well as disentangles the distinction from the declarative-procedural controversy.

After reviewing the tracking literature, Pew (1974) puts forth the proposition that subjects rely on abstract internal representations (i.e., motor schema) to organize movements in advance of action. During a lengthy and apparently random tracking task, a certain portion of the track was covertly repeated. On this repeated portion, subjects gradually improved with practice, even though their performance on the other (truly random) portions of the track did not improve. Pew (1974) also reported subjects were quite "unawares" either of the existence of the repeated portion of the track or their improved performance.

These results have several implications. Pew's subjects clearly had verbal access to neither "what" they were doing nor "how" they were doing it. Neither were they able to explain directly or indirectly what was going on; they were quite simply

"unawares" of both the relative and absolute changes in their tracking performance. Although the procedural-declarative as well as the directly-indirectly explicit distinctions are of little explanatory value, the distinction between explicit (that which one can talk about) and implicit (that which is implied by regularities in performance) clearly reflects the dissociation shown by Pew's (1974) subjects.

The utility of this distinction (as well as the futility of more popular alternatives) is also demonstrated by a recent experiment by Hendrick (1983). Flight simulator performance of 10 experienced pilots (with more than 1000 flying hours) and 10 novices (with less than 10 flying hours) was compared under two conditions. In the first condition, subjects flew a mission involving several turns and altitude changes. Subsequently, all pilots flew the same course but with the polarity of controls reversed. As might be expected, error data showed the clear superiority of the experienced pilots under normal conditions as well as the advantage of flying with correctly-rigged controls. However, the strikingly counter-intuitive result was that under the reversed-control condition, the novices' mean altitude errors were less than one quarter and heading errors less than half those of the experienced pilots.

There can be no doubt (at least among those who are even tangentially familiar with the breed) that experienced pilots have considerably more "explicit" knowledge of flying practices and procedures than do novices. (It is a great loss to science that Hendrick did not confront the experienced pilots with their relatively poor performance and record their verbal explanations.)

By reversing the controls, the experienced pilots greater implicit knowledge (which actually accounted for their superior performance under normal circumstances) was made to work against them. The fact that they were not able to overcome this impediment by employing their superior explicit verbal knowledge and "talking themselves through" the flight profile argues strongly against the assumed ascendancy of verbal intentions.

Explicit knowledge is not a "fully-contained subset" of implicit knowledge. As the last two experiments show, what subjects say and what they do may be independent. In fact, Berry and Broadbent's (1984) recent studies concerning subjects' accomplishment of "non-salient" computer control tasks showed a significant negative correlation between subjects' ability to perform tasks and answer questions about them.

The implicit-explicit distinction receives convergent support from Gazzaniga's (1985) studies with split-brain patients. The following is a particularly clear illustration of the dissociation:

> The experiment requires each hemisphere to solve a simple conceptual problem. A distinct picture is shown to each; in this case the left sees a chicken claw... the right... a picture of a snow scene. In front of the patient are a series of cards that serve as possible answers to the implicit question of what goes with what. The correct answer for the left is chicken; for the right a snow shovel. A typical response is that of P.S., who pointed to the chicken with his right hand and the shovel with his left. After his response, I asked him why he did that; he looked up and without a moment's hesitation said from his left hemisphere, 'Oh, that's easy. The chicken goes with the claw, and you need a shovel to clean out the chicken shed'. (p. 30)

The public relations homunculus has been well and truly "caught out." The distinction between the knowledge reflected by regularities in subjects' performance and the explicit rules

subjects espouse is important; it must be incorporated in the model.

1:7 ATTENTIONAL RESOURCE(S)

There are two distinctly different approaches to be considered in seeking to define functionally intermediate cognitive processes. One can start by assuming a single, unified and homogenous processing system and then sequentially carve out separate mechanisms which can be functionally differentiated from general processing activities. Alternatively, one can start by assuming the the system is entirely modular with no central processor and then seek evidence concerning the combinative characteristics and "rules of engagement" which govern interactions between independent modules. With the latter approach, the entire system must be built from the theoretical bottom up before questions concerning general mechanisms can be dealt with.

Both approaches have positive arguments and supportive evidence as well as able champions. Although the resolution of this fundamental controversy is clearly not possible, a brief review and contrast of the two positions provides a useful context for both the proposed model and subsequent experiments. (It should be noted that by separating intermediate from peripheral processes and also distinguishing between knowledge and attentional mechanisms, this thesis has already crossed the conceptual Rubicon from a strictly modular perspective.)

A classic experiment conducted at the end of the last century demonstrates the singularity of processing capacity assumed by "resource" models. Welch (1898) found cognitive tasks such as

reading and mental arithmetic interfered with the physical task of maintaining maximal grip pressure. Her related finding that more "difficult" passages or arithmetic problems caused greater reductions in grip pressure suggested the existence of strictly-limited general processing resources. Welford's (1952) single-resource, single-channel formulation and Broadbent's (1958) information processing model supporting filter theory implicitly assumed capacity to be singular, undifferentiated and strictly limited.

Information (as defined by Shannon and Weaver's (1949) theory of communication), was employed as a common metric for determining "difficulty" of a task (i.e., the amount of resource required to accomplish the task). Kahneman's (1973) studies suggested that rather than being fixed, capacity was elastic and, within certain limits, additional resources could be mobilized to meet increased task demands. Norman and Bobrow (1975, 1976) distinquished between cases in which performance is limited by lack of knowledge (i.e., "data") and those in which it is limited by the availibility of processing mechanisms (i.e., "resources").

The alternative, modular approach also has a number of historical precedents. In fact, "faculty psychology" reached its zenith in the early nineteenth century, only to be supplanted and discredited by "scientific psychology" at the end of the century (Worchel and Shebelski, 1983; Bourne and Ekstrand, 1985). However, this approach has recently been resurrected by a number of psychological investigators working in a variety of fields (e.g., Fodor (1983a, 1983b) in psycholinguistics and philosophy; Gardner (1984) in developmental psychology; Gazzaniga (1977) in

neurophysiological psychology; Hinton and Anderson (1981) in artificial intelligence and Allport (1980) in experimental psychology).

Allport (1980) espouses the most "modular" position and thus provides the clearest contrast with the "resources approach" just presented. He suggests the human mind, a concomitant of the human brain, is best conceptualized as a large number of independent "production systems" operating in parallel. Each of these computational units are specifically keyed to and activated by particular kinds of information:

> overwhelming evidence has accumulated for the existence of specialized neurons, responding selectively to particular (often quite abstract) invariant properties of the sensory input, as a major design feature of the central nervous system. (p. 33)

Allport's (1980) point is that each production system is content-dependent. Cognitive activities (which reflect the resonation of specific neural structures) are related to particular patterns of stimuli, not to the quantity of information to be processed. There is no need for a central processor to coordinate the activity of these modules; those most "excited" by extant stimuli simply become ascendant (This is very similar to the "pandemonium" model suggested earlier by the computer scientist, Oliver Selfridge (1959)). Control passes among modules as does conversation amongst a committee of experts. From this perspective, a central resource would have nothing to do. In Dennett's terms, the homuncular committee is ad hoc rather than bureaucratic.

Central capacity (i.e., strict resource) and completely modular approaches are based on different sets of assumptions.

However, there appear to be signs of convergence and synthesis. As Eysenck (1984) suggests:

> Even advocates of central capacity theory have been forced to admit that the original theory needs to be bolstered by a number of extra explanatory principles in order to account for the data. These include the demands on resources of task co-ordination (Duncan, 1979), the existence of automatic processes and the notion that capacity is elastic and flexible rather than fixed. (pp.66-67)

Eysenck is equally critical of complete modularity, claiming that "chaos" would be the probable result of such a system. In Eysenck's opinion, common resources are necessary to explain the co-ordinated and purposeful nature of human performance as well as interference between "entirely dissimilar" tasks. Fodor's (1983a) caveats concerning the non-modularity of central systems and Gardner's (1984) discussion of intermodular "waves" of development and higher order processes such as analogic reasoning appear to be complementary theoretical hedges.

Combinations of the two approaches seem both possible and desirable and have attracted many alternative formulations. Navon and Gopher's (1979) "Multiple Capacity Theory" provides a clear and influential example. Similarly, Kinsbourne and Hicks' (1978) conceptualization of "Functional Cerebral Space" purports to synthesize the two extremes by accounting for the performance and interference effects of both task difficulty and task similarity. Unfortunately, authors who offer theories based on multiple processing mechanisms often spell out neither the number nor nature of these separate resources; nor do they suggest ways of predicting a priori how task difficulty and similarity might interact. Working memory is a noteworthy exception.

Baddeley and Hitch (1974) originally elaborated the "working

memory" concept as an alternative to "short term memory". This concept is important for several reasons. By incorporating both a general processing component (i.e., the central executive) and specific processing mechanisms (i.e., the articulatory loop, the visuo-spatial scratch pad and potentially several others), working memory offers a synthesis of the central capacity and modular approaches. Because it combines two types of processing mechanisms, general and specific, working memory has the capability to explain interference effects attributable to both task difficulty and structural similarity. One of the advantages of this conceptualization is it provides a general framework within which questions can be operationalized and empirically tested. The results of these tests can then be employed to tighten "recursively" initial conceptualizations.

In early experiments, Hitch and Baddeley (1976) elaborated system characteristics in two specific areas: 1) capacity limitations and 2) the role of speech-coded information. They employed a dual task technique combining a verbal reasoning task (assumed to draw on the central executive) and articulatory side tasks (assumed to involve only the articulatory loop - i.e., repeating "the,the,the", cyclical repetition of "one-two-three-four-five-six" or three or four randomly-selected digits). They discovered any of these side tasks could be combined with the verbal reasoning task with only a modicum of detriment. However, performance on the verbal reasoning task was greatly impaired when the side task involved repeating a random string of six digits. Consistent with modular predictions, the lack of interference from the articulatory sidetasks suggested working memory's capacity was

not strictly limited. However, the clear evidence of interference caused by the recitation of six random numbers implied competition for a common processing component (viz., the central executive). Hitch and Baddeley's (1976) synthesis explains both aspects of their data:

> working memory is a general executive system with limited capacity for information processing with a peripheral articulatory system, used in rehearsal and concerned with speech coding... (but has) a relatively minor role in verbal reasoning. (p. 603)

Evidence supporting the division of working memory into separate components (and also supportive of the assumption of independent capacities) has been provided by others. Watkins, Watkins, Craik and Mazuryk (1973) found verbal memory was severely degraded by performing a visual pursuit-rotor tracking task during the retention interval when the amount of information stored was near capacity. Similarly, Reitman (1974) found short term memory for verbal material decreased when subjects were tasked to detect pure tones from white noise backgrounds during the retention interval, but decreased even more if the intervening task involved verbal material. The fact that non-verbal tasks can, to some extent, interfere with short-term verbal retention argues against a completely modular structure. The greater interference encountered when both primary and side tasks are verbal argues against an undifferentiated system.

Noting that across different task combinations, the articulation of random sequences of six digits caused considerable interference, but the articulation of shorter strings of digits caused only minimal interference, Hitch (1980) suggested that a task's sensitivity to random digit recitation might indicate the

relative contributions of the two components, the central executive and the articulatory loop. Consistent with this notion, Hitch presents evidence the central executive is involved in prose comprehension and mathematical problem solving. Baddeley (1983) presents evidence that although the accuracy of retrieval of information from memory is often insensitive to interference from a variety of secondary verbal tasks, the latency of retrieval appears to be very sensitive to interference.

The characteristics of the articulatory loop have been investigated extensively. Murray (1968) found that articulatory suppression eliminates the phonemic similarity effect and Baddeley (1976) found that suppression also removes the effects of word length but does not alter the recency effect. The loop itself is limited both temporally (Hitch (1980) suggests 2 seconds of verbal material and Baddeley (1983) suggests 1.5 seconds) and typically (i.e., it is exclusively reserved for verbal material). There is also evidence the articulatory loop is further subdivided into a relatively passive mnemonic device (i.e., the "inner ear") directly accessed by verbal inputs and a more active processing component (i.e., the "inner voice") (Baddeley, 1983; Hitch, 1980). This distinction is not, however, critical to the experimental work to follow.

Another component of working memory, the visuo-spatial scratch pad has also been studied. Brooks' (1968) classic demonstration of differential interference between task and response modalities provides a clear example. Response latencies were greatest when a verbal task (stating whether each successive word in a familiar phrase was a noun) was combined with a verbal

response (saying "yes" or "no") or when a spatial task (stating whether each succeeding corner in an "imagined" block letter was located on the extreme outside) was combined with a spatial response (pointing to irregularly spaced Y's or N's).

Similarly, Segal and Fusella (1970) contrasted the interference caused by visual and auditory images with visual and auditory signal detection tasks to show strong structural interference effects. Although Baddeley and Hitch (1974) incorporated the visuo-spatial scratch pad as another slave mechanism in the working memory system, its empirical examination has been relatively neglected. Kosslyn's (1978, 1980, 1984) studies of mental imagery dovetail nicely with the general constraints placed on slave mechanisms by the working memory concept. Kosslyn (1984) presents evidence to suggest the spatial medium is temporally-limited (processing activities per unit time) and is connected to a specialized, spatially-designated long term memory store. Although this system is unaffected by verbal limitations (i.e., word length or phonemic similarity), it has comparable spatial limitations (i.e., representational scope and grain). While the evidence for a separate spatial mechanism is strong, it has not been empirically investigated in the experiments which follow.

Neurological evidence for specific processing mechanisms is also beginning to emerge as test procedures and measurement techniques become increasingly sensitive and sophisticated. A recent experiment by Aarts, Binnie, Smit and Wilkins (1984) with 46 patients exhibiting "subclinical" epileptiform seizures while performing two short term memory tasks (one verbal and the other

non-verbal) is an example. Although there were no externally visible signs of these "larval seizures," task performance was affected in predictable ways. Spike discharges occurring during stimulus presentation were the most disruptive but those occurring during response execution were "without demonstrable effect." Even more interestingly, left side discharges were associated with errors in the verbal task and right side discharges impaired performance on only the non-verbal task.

Although this study suggests a neurological basis for separate modules, evidence supporting the central executive remains primarily functional rather than physiological. It is possible that this "component" (which Baddeley (1983) refers to as the area of residual ignorance) is actually an epiphenomenal reflection of shared characteristics of cognitive activities occurring at many different neurological sites. It is surprising, however, that such a diffuse and ephemeral entity should respond to experimental manipulations so predictably and consistently. The distinction between general and specific attentional mechanisms will be included in the model.

1:8 THE META-MODEL

A number of possible functional distinctions have been presented and discussed. After a brief summary of these, an initial meta-model can be presented which integrates these functionally-significant distinctions. The first distinction concerned differentiating intermediate cognitive processes from peripheral input and output systems. Although such "stage" or "horizontal" separations are frequently (and occasionally usefully)

made, the assumptions of complete independence and strict seriality become untenable when applied to complex or higher-order processes. Baddeley (1983) suggests current developments support:

> blurring of the distinction between memory and other cognitive processes. Working memory uses components of many other cognitive systems, notably those involved in perception and action in general. (p. 321)

However, there are practical reasons for making such distinctions, particularly when employing dual task techniques. Peripheral interference effects must be isolated and controlled in order to accurately identify the interference occurring within and between intermediate cognitive processes. For this reason, separate input and output channels will be represented in the model and, to the extent possible, controlled in the experiments.

A distinction receiving a great deal of support from a wide variety of sources, reflected different processing modes. The parameter-specification automaticity framework proposed by Neumann (1984) was employed to synthesize many other dual process formulations. Performance was assumed to be either more or less "automatic" based on the relative involvement of two conceptually-distinct components (i.e., skills or knowledge and attentional mechanisms). These two components were proposed as the initial primary distinction between intermediate cognitive processes.

Further functional distinctions were considered for each of the conceptual components. Skills might be derived from practice or alternatively may be influenced by innate structural characteristics of the information processing system. Tradeoffs between practice and compatibility suggest their functional

equivalence. This argues against the inclusion of this distinction in the model. Likewise, it was argued different informational formats (i.e., continuous- discrete, analogical-propositional, or procedural-declarative) were functionally equivalent and therefore unnecessary.

The single significant distinction involved the difference between explicit and implicit knowledge. Explicit knowledge was defined in general terms to include material which subjects could only talk about as well as that which they could clearly and concisely articulate. In contrast, implicit knowledge was defined as the internalized relation-structures implied by regularities in subjects' performance. Although there may be considerable overlap between the two, explicit knowledge is not a fully-contained subset of implicit knowledge. In many cases, these two forms of knowledge are functionally independent (and occasionally even counter-dependent). This distinction is essential.

A similar distinction was made within the other component (viz., limited-capacity, temporally-constrained, and agnostic attentional processing mechanisms). Baddeley and Hitch's (1974) formulation of the working memory concept was adopted as a framework because it included both a single, general-purpose processing mechanism and potentially several separate, domain-specific processing mechanisms. Baddeley and Hitch (1974) and Hitch and Baddeley (1976) suggest two such slave mechanisms, the articulatory loop and the visuo-spatial scratch pad, but also allow for others. The articulatory loop, the mechanism which includes both the "inner voice" and the "inner ear", and specializes in verbal rehearsal and processing or holding

speech-coded information, is by far the most thoroughly investigated subsystem.

Although not explicitly presented, the compatibility of the distinctions within each component should be apparent. The articulatory loop, an attentional mechanism, is likely to have direct access to explicit (i.e., verbally-coded) information. (Likewise the visuo-spatial scratch pad and any other specialized processing mechanisms are likely to be directly linked with their own code-specific memories.)

The link between the central executive (a general processing resource) and general (i.e., implicit) knowledge is less clear. From a modular view, this question could only be asked after each separate module had been identified and empirically isolated from other ongoing processes. An alternative approach is to start with the assumption of a homogenous system and systematically demonstrate the functional distinctiveness of separable modules. With this approach the influence of the general processor necessarily also includes all unspecified processing modules. For complex, problem-solving type tasks, this seems a more practical strategy than attempting to control exhaustively the effects of a unknown number of modules (as adopting a bottom-up modular stategy would require).

The meta-model derived is depicted in Figure 1-1 and will be briefly explained. In addition to the two major intermediate processing components (skills and processing mechanisms) already directly proposed, two other components have been included in the model. The first of these is the motor output system. This component includes all activities which are necessary for the

HUMAN INFORMATION PROCESSING SYSTEM

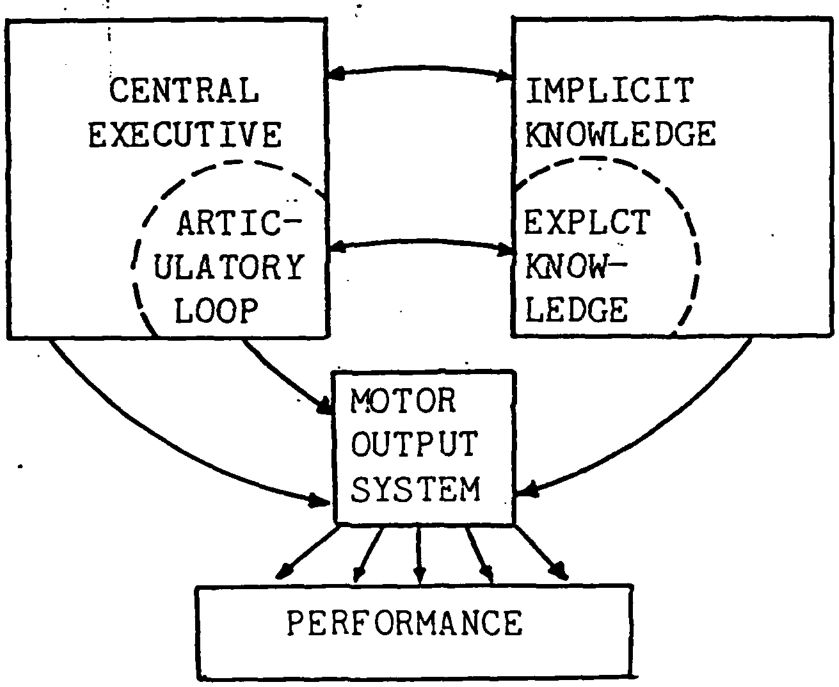


Figure 1 - 1

execution of the selected response. To employ a "pipeline" metaphor (Broadbent (1958), they are "downstream," or from a hierarchic perspective (Gallistel, 1980), below the intermediate cognitive processes discussed here.

Three potential influences are depicted. The middle arrow represents the direct influence of the articulatory loop (particularly the "inner voice" portion) on motor activities. This influence reflects the activities involved in "talking oneself through" a task. The influence of the non-verbal general attentional mechanism is shown by a separate arrow (to the left). Although this influence involves as much concentration and effort as self-instruction, it does not involve words (e.g., a novice's attempts to thread a needle). A third influence, that of skills or knowledge, is depicted as another arrow (on the right). The way in which these influences interact is an empirical question which will be investigated in the experiments which follow.

However the motor output system is influenced, its activities become visible and, more importantly, measurable in the context of specific and immediate task environments. This observable output in a specific task context is performance. Subjects, as well as experimental psychologists, are interested in monitoring performance. Two separate "feedback" channels, one to each of the types of intermediate components, are depicted in the model. Much of the evidence presented in support of the initial distinction between the two processing modes implied similar configurations. The feedback channel on the right represents the rapid, pre-attentive and unconscious acquisition of global, affective, literal information (or "preferenda" as Zajonc (1980) suggests).

In contrast, the left channel represents the relatively slow, purposeful, analytic selection of detailed, cognitive, and often symbolic information (or "discriminanda" in Zajonc' (1980) terminology).

This model is a spatial representation of the functional distinctions presented in this chapter. The utility and sufficiency of the model rests on its power to suggest, predict, and incorporate the results of the experimental work which follows.

1:9 SUMMARY

This thesis contains a functional examination of the intermediate cognitive processes involved in the performance of meaningful, complex tasks in moderately-constrained task environments. Limitations inherent in traditional empirical methodology can be ameliorated by initially adopting aspects of alternative contemporary approaches (i.e., contextualism and boot-strapping). The approach adopted here involves three steps. This chapter has been devoted to establishing several necessary functional distinctions. These distinctions were combined to form the initial "meta-model" on which the approach fundamentally depends. This model will now be applied to conceptualizing and technically developing appropriate experimental equipment, tasks and procedures (Chapter 2) and suitable measurements and statistical analyses (Chapter 3).

A FUNCTIONAL EXAMINATION OF INTERMEDIATE COGNITIVE PROCESSES

CHAPTER TWO

EXPERIMENTAL PROCEDURES

2:1 LABORATORY EXPERIMENTS AND BEHAVIOURAL INTEGRALITY

The purpose of an experiment is to generate "system-critical" data. Experiments design involves a series of choices. The object is to balance the experiment's power to yield significant and interpretable results with the applicability of those results to tasks outside the psychology laboratory. Before explicating the choices made for the experiments which follow, a review of these two considerations is useful.

Basically, internal validity concerns the rigor of the experimental design and procedures. Influences from two types of factors require control. "Obscuring" variables randomly influence dependent measures. Inferential statistics are derived by comparing the variance explained by independent (i.e., experimentally-controlled) variables with the total variance in criteria. Obscuring influences often cause equivocal results i.e., results which are not statistically significant.

An even more serious threat to an experiment's efficacy is posed by "confounding" variables. These represent influences which also affect criteria, but do so in a systematic rather than random way. Confounding variables often yield apparently significant results, but because they violate fundamental assumptions on which statistical inferences are based, results are uninterpretable. The remedy to both problems is the same: greater experimental control. As Mook (1983) recommends: "the strategy to see anything clearly is this: ...arrange matters so there is nothing else to see, then look

...to understand, simplify and observe" (p. 10).

Threats to external validity (i.e., generalizability) can also be divided into two categories: those that involve population validity and those that involve ecological validity (Bracht and Glass, 1968). Using college freshmen as representatives of the rest of humanity is one of the most common, as well as most egregious, violations of population validity. Ecological validity concerns the representativeness of the context and substance of the task itself. In spite of the widespread recognition and emphasis this issue receives, explicit guidelines for developing ecologically-valid tasks are rare.

Broadbent (1984), in fact, explores the theoretical and practical implications of adopting "perfect simulation" (the ultimate in ecological validity) as a strategy for investigating the effects of drugs on performance. He argues convincingly that this approach is unworkable and suggests adopting a test profile strategy instead. Such a "profile" would include a variety of the types and levels of skills and abilities involved in everyday activities. Although there are many laboratory tasks which reflect perceptual and psychomotor skills, as well as purely cognitive, problem-solving abilities, experimental paradigms which tap "behavioural integrality" are conspicuous only by their absence.

Integrative processes (e.g., strategy or judgement) have often been identified as being critical to the performance of real tasks (e.g., James, 1892; Craik, 1943; Bartlett, 1958; Neisser, 1976; Roscoe, 1980; Jensen, 1982; or Wood, 1983). However, only recently have the cognitive complexities presented by tasks which simultaneously involve perceptual, decisional and performance

problems been empirically investigated. Brown, Tickner and Simmonds' (1969) demonstration of different effects of a verbal side task on two aspects of a driving task and Broadbent's (1971) empirical support for a functional distinction between upper and lower processing mechanisms are two early examples. The identification of individual differences in processing style (e.g., Cooper's (1980) distinction between analytic and holistic perceptual processors, Damos' (1983) segregation of individuals by their "natural" bead sorting strategies or Gopher's (1982) isolation of "tactical thinking ability") often employs integrated tasks and complex measures of performance. However, reviewing these (as well as other similar studies) does not provide an immediately obvious answer to the question "what makes an integrated (and ecologically valid) task?".

The lack of a general theory relating to this issue within experimental psychology, forces a search elsewhere. One approach might be to look at tasks people choose to do. A refinement of this strategy, is to look at "jobs" and discern which attributes are associated with higher levels of motivation and effort. The "job diagnostic" approach developed by Hackman and Lawler (1971) has been usefully applied to many different organizational and social settings (e.g., Hackman and Oldham, 1975; Porter and Porter, 1982). The basis of this approach is that certain core job characteristics evoke psychological states which combine to determine job outcomes. To the extent an experiment can be viewed as a "mini-job," the same characteristics that "enrich" a job should make an experiment both more motivational and more representative of the types of jobs which are becoming increasingly

important in the world outside the laboratory.

Hackman and Oldham (1975) suggest three key psychological states: the perceived meaningfulness of the task, felt responsibility and knowledge of results. It is the product (viz., the positive interaction) of these which best predicts effort. The perceived meaningfulness of a task is reflected by the sum of three factors: skill variety, task identity and task significance. Subjects' "felt responsibility" is proportional to the amount of control subjects perceive. (As Langer (1982) clearly demonstrates, it is the perception, or even illusion, of control rather than actual control which is of the greatest psychological significance.) The final component, knowledge of results, reflects subjects' ability to get direct, unmediated, feedback from the task. Adams' (1971) work demonstrates the essential nature of this factor.

The multiplicative combination of these three dimensions has important implications. The motivational potential of a particular task is limited by its weakest characteristic. If any one of the three is low, the product will also be low. If a task is meaningless, giving subjects greater autonomy or more feedback cannot compensate. Equally, if subjects feel no responsibility for the results or if they don't understand the results, minimal effort is likely. Games are often used to exemplify the motivational power of "enriched" jobs. Perhaps a game might prove a useful tool for investigating the performance of integrated tasks. Broadbent (1984) concurs: "It is probable that the development of better measures of performance, based on video games, will make it easier to test strategy."(p. 8S)

2:2 VIDEO GAMES

A general discussion of computer games provides background information for understanding the game developed for this thesis. The next few pages provide a brief account of the growth of computer games, several of their inherent (and psychologically interesting) characteristics and some of the ways video games have already been employed in psychology.

Gutman (1983) supplies a useful overview of the development of computer games. Steve Russell, a researcher at Hingham Institute, Cambridge, Massachusettes developed a computerized battle between two torpedo-firing space ships in 1962. When transfered to Stanford in 1969, he took the game and a growing number of disciples with him. In 1971, Russell and a student, Nolan Bushnell, marketed a commercial version, but due to its complexity it was a financial failure.

Bushnell went to Japan and founded his own company (ATARI), and within a year had developed the simplest game imaginable: PONG. This highly simplified electronic ping pong game required two players to move electronic paddles along a single dimensions to volley a rapidly moving "pong ball". The prototype broke down within hours of being installed at Andy Capp's Bar in Sunnyvale, California; the coinbox was overstuffed with quarters. From these beginnings, video games developed rapidly and spread quickly, gaining an increasing number of enthusiasts. In the mid 70's, when several companies offered computerized games which attached to home television sets, the popularity of video games increased even more rapidly.

In 1979, the newest game, "Space Invaders", earned over one

billion dollars. Although it was very successful, Space Invaders contained several aesthetically undesirable characteristics. It was considered by many to be a game requiring only "lower-level" psycho-motor skills (i.e., in the "twitch" category). It was also overtly aggressive (players moved a fixed cannon left or right to "zap" bomb-dropping, relentlessly-approaching waves of alien invaders). The "macho" image associated with war games as well as the arcades that housed them and the actual game structures did not appeal to many potential players, especially women (Esh, 1983).

A new game introduced in 1981 required both analytic reasoning and strategy as well as quick reflexes, yet like PONG, was simple to learn and not overtly aggressive. PACMAN was so successful, computer game popularity and revenues increased even further:

> In 1981, video games reached mania status, earning twice as much as all of Nevada's casinos and three times as much as the TV revenue and gate receipts of professional football, baseball and basketball combined. (Gutman, 1983, p. 117)

Although the popularity of video games has waned since 1983, when gross receipts in the U.S. topped 6 billion dollars, their following is still very substantial.

As both an individual and social phenomenon, video games have developed so rapidly and so recently that academic description, discussion and application have only begun to be reported. Loftus and Loftus (1983), referring to video games as "the 25 cent addiction" explain their popularity in behavioural reinforcement terms. They attribute the effort players willingly exert to the motivation elicited by the opportunities video games afford. These include the opportunity "to score", to compensate for previous poor

performance, and to receive continuous, immediate and objective feedback. Ingber (1983) reports that as arcade games become more difficult, some players show marked physiological responses (cf., Kahneman's (1973) studies):

> Before the test began, the patient's blood pressure was a comparatively normal 134/89. Within minutes, however, it had risen to 183/25 while the blood output of his heart dropped to half its optimum level... The hard part is learning to control the anxiety created by the intense, combative nature of the games... games cause a great deal of arousal... but so does driving a car. The video game is just one provocateur in our environment. (p. 81)

Computer games can be both fun and exciting, but as is often the case, such activities attract "responsible" concern and hasty censure. In 1982 the New York Times printed an article in which the Surgeon General of the United States expressed grave concern about the detrimental effect video games might be having on the development of the next generation.

One of the few credible studies on this topic was reported by Gibb, Bailey, Lambirth and Wilson (1983) and suggests the influence of playing video games on personality is slight. Their conclusion was based on interviews conducted with 280 randomly selected subjects on departure from video arcades in 5 states. Scores on six personality dimensions as well as information concerning total game experience and frequency of play were collected. There were no significant differences between their sample and appropriate population norms on any of the dimensions. The total sample was divided by gender, and the effects of experience and frequency of play on each of the six variables were explored. Of the 24 possible correlations only two were significant: females who had been playing longer had a slightly higher achievement motivation

than those who had just recently started playing. Gibb et al.'s (1983) results also significantly contradict the "fanatic" stereotype of video game players:

> Those high in obsessive-compulsive traits may not have found the games attractive because successful performance on many games depends on skill requiring flexibility of response rather than mastery of a rigid response pattern. (p. 163)

One worrying sociological aspect of the current video phenomena involves the disproportionate participation of males and females (industry figures suggest a 9:1 male to female ratio). If useful (i.e., generalizable) skills are gained by playing video games (e.g., dynamic problem-solving strategies, spatial abilities or simply hand-eye coordination), then differential play in the arcade may result in differential opportunities in the workplace. Esh (1983) suggests girls and boys enjoy different games and male game designers perpetuate the bias by creating male-oriented games. Whatever the reason, Elizabeth Loftus' (1983) poignant recommendation that "parents should worry less about their sons playing the games and more about their daughters not playing" (p.8) seems appropriate.

The experiment by Aarts et al., (1984) showing differential interference of left and right hemispheric epileptiform seizures on verbal and nonverbal tasks employed a computer game format. Ingber (1983) reports another clinical application of video games. A number of Veteran's Administration hospitals have recently employed computer games to help retrain stroke and brain trauma patients. A staff psychologist explains the why:

> the games demand you remain alert, keep track of rules and develop a degree of hand-eye coordination and visual scanning ability ...most importantly patients like them. (Ingber, 1983, p.81)

Baumeister (1985) reports an interesting application in his study of the "choking" phenomenon (i.e., decrements in performance he attributes to increments in motivation). After first surreptitiously observing the performance of a number of "accomplished players" (all 13 years or older), Baumeister offered each a free game to participate in his research. He recorded their names and gave them one chance to score as many points as possible on the game on which he had covertly recorded their previous performance. Scores declined by 25 percent. However, when Baumeister (1985) repeated the experiment with younger subjects (under 13 years old), he found overt observation actually improved scores.

Jones, Kennedy and Bittner (1980) attempted to apply computer games directly to the problem of performance prediction and personnel selection. They note several of computer games' inherent qualities make them "pragmatically attractive" as selection tools. Computer games often involve complex skills, allow improvement with practice over relatively long periods of time, are self-motivating, and involve high but variable speed constraints. After reviewing the performance of military recruits on 10 different commercial video games, they found that it required an average of 8 hours of practice, for performance to "stabilize" (viz., for the trial-to-trial score correlations to exceed .90), but that:

> It seems video games do not all depend on the same underlying skills and abilities, since the correlations between tasks are in some cases quite low. (Jones et al., 1980, p. 467)

However, other evidence they present suggests a tendency for performance on certain games to "converge" with practice despite considerable surface dissimilarities (e.g., Air Combat Maneuvers

and Breakout). Their tentative conclusion is that video games might (someday) provide a useful predictor of complex "operational" skills.

Cravford (1983) is rather more enthusiastic, however, in touting the potential application of computer games to teaching:

> Games are more than just a way to have fun. They're the most natural way to learn ...they've received the seal of approval of natural selection ...The question 'can games have educational value?' is absurd. It is not games but schools that are the new fangled notion, the untested fad, the violation of tradition ...learning experience from an arcade screen is direct, immediate and compelling. (pp. 79)

The "pragmatic attractions" of adapting computer games for psychological research are obvious. What are not so apparent are the obstacles which impede adaptations. Here are several: 1) computer games tend to provide only a single global measure of performance (i.e., the score); 2) to provide greater interest, most games rely on randomization functions to change the game a little each time (this adds unwanted variance to performance) and 3) the duration of play is often positively related to players' skill (i.e., better players get more practice).

None of these problems are insoluble, but to "fix" them, one has to get "inside" the game. In addition to legal and financial restrictions (viz., copyright laws) and the necessity to understand the machine code in which popular games are shrouded, most games include elaborate defences against having their computational secrets stolen. The alternative of starting entirely from scratch and creating a game that is both fun to play and suitable as an empirical tool requires greater naivety than courage. The psychological literature reveals few real attempts.

Fortunately, one does not have to start entirely from

scratch. There are many useful texts which teach BASIC programming and suggest useful applications (e.g., Morse, et al., 1983 or Vickers, 1982). More directly useful are the plethora of pamphlets written for (and sometimes by) children, which show how relatively few lines of BASIC can produce playable games (e.g., James, Gee and Eubank (1983)). Although these games clearly lack the "flash" of commercial products, many are fun to play and involve psychologically-interesting activities. The great advantage of these games is their accessibility; they can be altered in any way the researcher desires. Another problem, however, is created by reliance on BASIC; it is very, very slow. The more variables, the slower the program runs. In addition to the decidedly unnatural character of playing a video game in slow motion (i.e. with pauses of several seconds between movements), such a lack of pace has psychological consequences.

One of the aims of this research was to investigate tasks of "behavioural integrality" (viz., those which involve processing problems of different types and levels). After their review of discrete movement studies, Howarth and Beggs (1981) suggest speed-error-tradeoffs are nearly linear for a wide range of tasks with response rates between 40 and 160 times per minute (i.e., one response every 375 to 1500 msec). Rabbitt (1981) is an outspoken advocate of studying performance in conditions where such tradeoffs occur. He suggests that not only is the existence of such tradeoffs necessary for certain psychological interpretations of results, such tasks are also more ecologically valid:

> In real life, people often have to respond to continuous series of events rather than discrete signals. These events may occur at more or less predictable intervals. To perform optimally, man must learn the characteristics of such sequences and

> accurately predict and estimate time intervals in order to prepare himself to respond at precisely the moment when signals fall due. (p. 158)

(Gibson (1950), Bartlett (1958) and Neisser (1976) have posed similar arguments in support of the greater representativeness of cyclical processing activities.)

There is another theoretical reason to constrain performance to the tradeoff portion of the speed accuracy curves. Video games provide an opportunity to compare tasks that utilize the same displays (viz., the CRT representations) and controls (viz., discrete keys) but differ substantively (viz., in the number and nature of the intermediate cognitive processes involved). A useful technique often employed in dual task studies is to plot changes in the performance of one task as a function of performance on the other (e.g., Norman and Bobrow, 1976; Sperling and Melcher, 1979; Navon and Gopher, 1979; or Kinchla, 1980).

The resultant performance operating characteristic (POC) is a spatial representation of possible performance combinations of the two tasks. In order to plot such curves, subjects must be induced to shifts resources from the performance of one task to the other. Although it has been argued that shifts may be affected by changing task difficulty (e.g., Kantowitz and Knight, 1976), others point out that difficulty manipulations often change the way the task is performed (Navon and Gopher, 1979) and suggest "priority" alone be employed (Norman and Bobrow, 1975).

Norman and Bobrow (1976) also point out performance may be limited by either the availability of resources (processing mechanisms) or data (either environmental information or the knowledge structures necessary to interpret it). If extra

resources result in improved performance, resource-limitations are assumed, otherwise performance is assumed to be data-limited. The point to be made is this: time is a general resource (i.e., it contributes to many processing activities). Ensuring performance occurs along the tradeoff portion of subjects' speed accuracy curves, helps justify the assumption of full utilization of resources and subsequently justifies stronger interpretations.

2:3 SAVE THE WHALE

A video game was developed by incrementally incorporating aspects from several BASIC programs within the constraints outlined above. The result was an arcade-type game which was both entertaining and experimentally useful. It was relatively simple to learn (most subjects "caught-on" within 10 minutes) yet very difficult to master (only twice in over two thousand trials did subjects earn maximum points). Subjects controlled the direction of movement (i.e., a "first-order" control system) of a single character along either of two dimensions (i.e., vertical or horizontal). The game took place over a "fixed" period of time and successful performance required the coordination of many activities.

Cyclic dual task priority instructions were employed to induce intentional shifts between two substantively different tasks (neither of which involved bombs or bullets). With the aid of the Spectrum M-Coder, many BASIC commands for collecting frequencies and printing characters were converted to machine code. This (together with the conversion of almost all game variables to discrete memory locations (Sinclair, 1983)) reduced the average cycle time (i.e., the time required for the computer to read

subject's inputs, move characters accordingly, record the occurrence of designated events and produce appropriate visual and aural outputs) to about 700 msec (well within the limits suggested by Howarth and Beggs (1981)). The resultant Save the Whale Game was played on a 48 K Spectrum microcomputer. (An annotated printout of the BASIC program is listed in Appendix A.)

The monitor screen displayed a standard 22 X 32 cyan matrix set in a dark blue border and containing four clusters of icebergs as shown in Figure 2-1. (Although a 16 inch black and white television was used for the first experiment all subsequent experiments used a 19 inch colour monitor.) Subjects controlled the direction of movement of a blue whale (initialized at the centre of the screen) by pressing one of four keys on the computer keyboard. The index and middle fingers of both hands were overlapped on the keyboard to produce a direct spatial mapping for responses as shown in Figure 2-2. The "2", "E", "S" and "Q" keys were employed. Subjects could change the whale's direction once each cycle by holding down the appropriate key. If subjects were pressing the key corresponding to the direction the whale's travel or failed to press any key, the whale moved one space in the direction it was heading.

One particular characteristic of the controls should be mentioned. Because the computer only read subject's key press once each cycle, there was a variable delay of 150 to 900 msec from the subject's inputs and the whale's responses. To control the whale, subjects had to press and hold the appropriate key rather than repeatedly tap the key as is common for many arcade games.

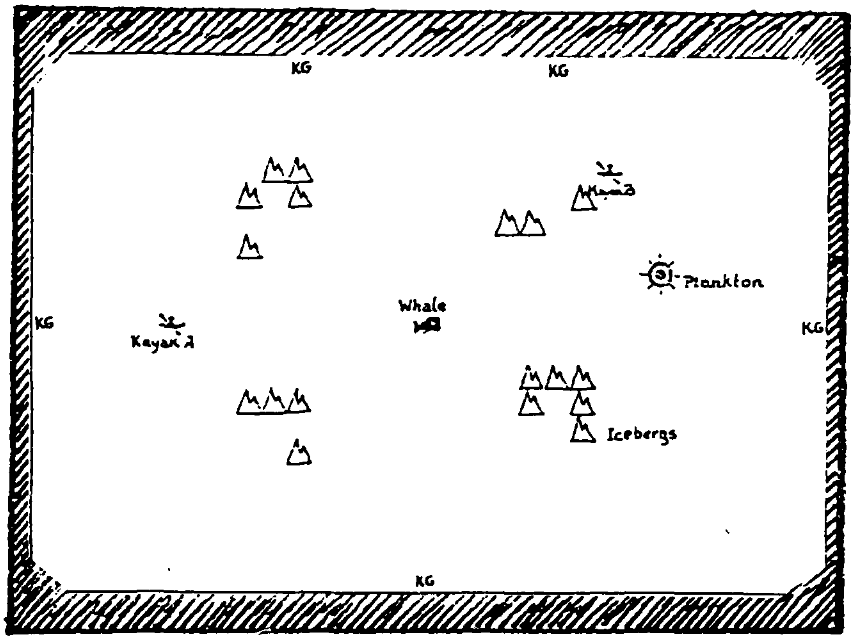


Figure 2-1

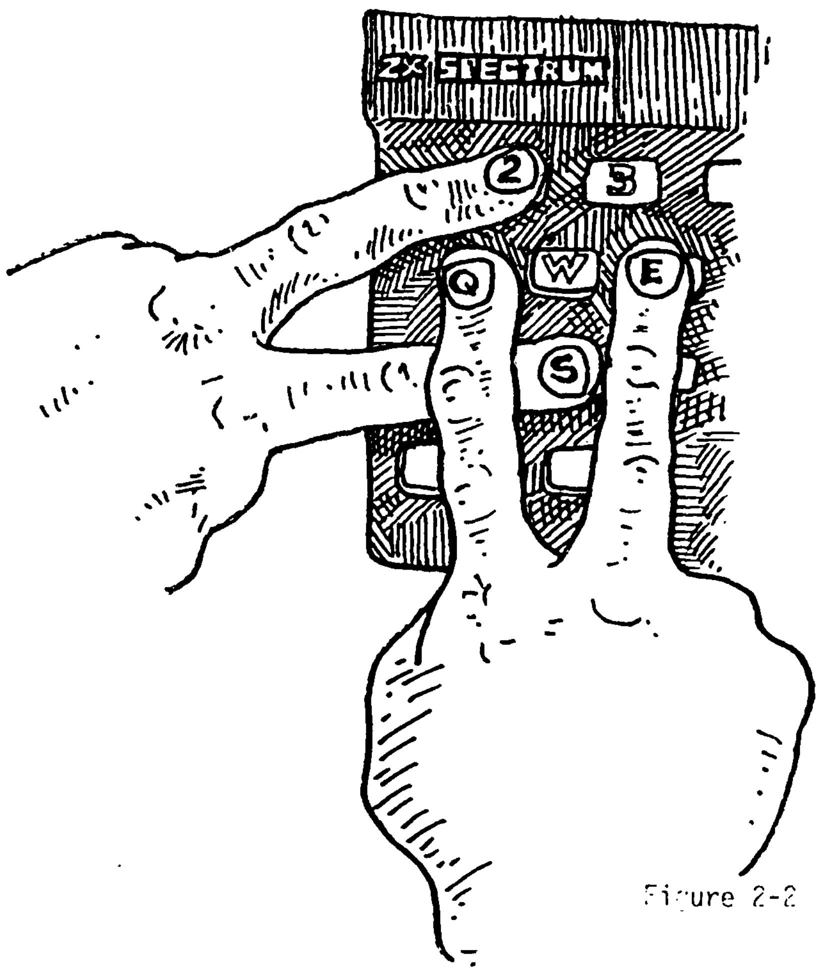


Figure 2-2

Subjects seemed to adapt to this characteristic quickly.

Thus subjects could control their whale's movement in either of two directions. However, subjects could not change the whale's speed or make the whale move diagonally, stop or cross the screen border. Within these constraints, the whale was to pursue either or both of two substantively different tasks: eating plankton and wrecking kayaks. The differences between these tasks are of fundamental importance and will be described in some detail.

2:3a The Dual Tasks

The two different tasks were originally chosen to reflect differences in "higher" and "lower" level processing. Brown et al.'s (1969) demonstration of the differential effects of a verbal side task on two aspects of the primary task of driving served as a model. Brown et al. (1969) found that although verbally answering questions interfered with drivers' decisions, it had no effect on their psycho-motor performance. The kayak task was to reflect decisional processes and the plankton task, primarily psycho-motor activities. However, from the earliest pilot studies it was apparent this simple distinction was both inadequate and inaccurate.

The automaticity formulation offered by Neumann (1984) and incorporated in the meta-model presented at the end of the last chapter, provides a richer and more useful framework for contrasting the two tasks. Neumann (1984) maintained tasks could be represented by their parameter specification requirements. The information processing "load" was thus the number of parameters to be specified per unit time. Tasks requiring too many parameters to be specified in too short a period of time are impossible, and

those that require too few are trivial. Tasks which impose moderate processing loads are the most psychologically interesting. Within the domain of "moderate demands", two types of task may be substantively differentiated: those with only a few parameters but requiring frequent filling and those with more parameters but requiring less frequent specification. (The number of different parameters to be specified provides a rough indication of task complexity.)

It was further suggested that the source of specification provides an additional (and perhaps orthogonal) substantive distinction. For those tasks with consistent relation structures, internal representations (i.e., mental models) are developed to specify parameters more or less continuously. However, if the task lacks constant relationships, parameters must be specified by resort to a secondary system (i.e., attentional mechanisms). This dimension reflects the task's uncertainty and is inversely proportional to the task's susceptibility to automatization. (This dimension should not, however, be confused with the uncertainty subjects report; consistent relation structures, particularly for complex tasks, are much more likely to be implied by regularities in performance than in the explications of performers.) Along these dimensions, the plankton was a simple but uncertain task and the kayaks were a complex but certain task. Each will be described in greater detail.

The plankton task was simple but uncertain. A single mass of green flashing plankton was initialized to the right of the whale as shown in Figure 2-1. ("Mass" is perhaps the wrong word since each of the characters in the game occupied a single, 8 X 8 pictel

space.) The plankton proceeded in a diagonal psuedo-random walk to the right, drifting slowly to the top of the screen, reversing direction and drifting down-screen to the bottom, then reversing direction again. It disappeared from the right screen border and immediately reappeared at the extreme left screen border and continued its zig-zag drift to the right. While its general path was repeated in most experiments, the specific sequence of plankton movements was generated by complex formulas and was virtually unpredictable.

A single symbol was used to represent the plankton, so there was no indication of its direction of movement. The task was particularly frustrating because the plankton occupied only one space and the whale moved one space each cycle (ergo: it was impossible for the whale to "eat" the plankton half the time; this could be referred to as "the checkerboard effect"). It was relatively obvious how to score on the plankton task (viz., by staying near the mass and constantly turning toward it), but accomplishing this required considerable concentration. When the whale was successful, the computer emitted a low-toned beep (viz., a belch) and the score displayed at the top centre of the screen was increased by the appropriate number of points.

In contrast to the plankton, the kayak task was more complex but completely predictable. Kayaks were "generated" at one of five locations along the screen border ("KG" in Figure 2-1) in a fixed order. The probability of a kayak appearing during each cycle was about 6 percent. On average, kayaks remained on screen for 12 cycles. This resulted in an apparently random mix of conditions (i.e., there were no kayaks present about 34 percent of the time,

one present 39 percent, two present 20 percent, three present 5 percent and very rarely four were present).

Once generated, kayaks followed one rule: they moved toward the whale. If they were either horizontally or vertically aligned with the whale, they moved one space horizontally or vertically (e.g., kayak A in Figure 2-1). If not aligned, they moved one space vertically and horizontally (i.e., diagonally as would kayak B in Figure 2-1). If the whale was not heading directly away from a kayak, the kayak moved closer to the whale on each successive cycle. As the plankton, the kayak symbols gave no indication of their direction of travel. Kayaks remained on the screen until one of two things happened: they encountered an iceberg and sank (as is about to happen to kayak B) or reached the whale and harpooned it. Subjects gained points for the former and lost an equal number for the latter. There were distinctive sounds for each contingency: a high-pitched "squeal" when a kayak crashed into an iceberg or three rapid tones of decreasing pitch if a kayak harpooned the whale. In either case, the kayak disappeared and an immediate adjustment was made to the score display.

2:3b Other Aspects of the Game

Although the whale's relationships to the plankton and kayak were most directly important, several other features also warrant comment. A kayak moving into a iceberg crashed; however, if the whale moved into an iceberg, the iceberg silently vanished. Although this contingency seemed readily apparent, some subjects did not discover it until destroying dozens of icebergs over several trials. Once destroyed, icebergs were lost for the remainder of the trial, but reappeared in the same location at the

beginning of the next trial. If the plankton moved into an iceberg, the plankton disappeared. While it was "under" the icebergs (sometimes for as long as six cycles or about 4 seconds), it could not be eaten by the whale. The plankton usually emerged on the opposite side of a cluster of icebergs. If the plankton and a kayak were co-located, nothing happened; one symbol simply overprinted the other and there was no effect on either.

Trials lasted about three minutes and consisted of 251 cycles for the first experiment, but were shortened to 217 cycles for later experiments. The two tasks were combined in three ways: either one or the other was afforded "priority" or they were given equal priority. This was accomplished by awarding differential points for performance of the two tasks. As Loftus and Loftus (1983) recommend, points for discrete events ranged from 10 to 100. For example, on a "plankton priority" trial, plankton was worth 100 points per bite and crashing or being harpooned by the kayaks was plus or minus 10 points. Points were simply reversed for the "kayak priority" trials (i.e., plus or minus 100 points for kayaks and 10 for plankton). An equal number of points (50) were assigned to all contingencies for "equal priority" trials.

Although this scoring system resulted in three distinctive priority conditions, total points scored were not directly comparable between priority conditions (i.e., most subjects scored more points on the plankton priority trials). The priority was always explained in instructions before the initiation of each trial. Half the subjects started with the kayak priority first, followed by an equal priority trial and then a plankton priority trial. The other subjects accomplished the trial priorities in the

reverse order. Thus each subject completed one trial of each priority on each successive set of three trials.

At the conclusion of each trial, the video screen blanked and then displayed the end of trial data. Subjects copied the number of kayak crashes, tonnes of plankton eaten and total points earned on a score sheet with their name at the top. At the same time an attached printer clattered out a dozen lines of coded performance data. After recording their scores, subjects input a code and the game was re-initialized with the priority instructions for the next trial. The number of trials varied from experiment to experiment (from 15 to 27) but in all cases, subjects were given short breaks after every 9 trials (30 minutes).

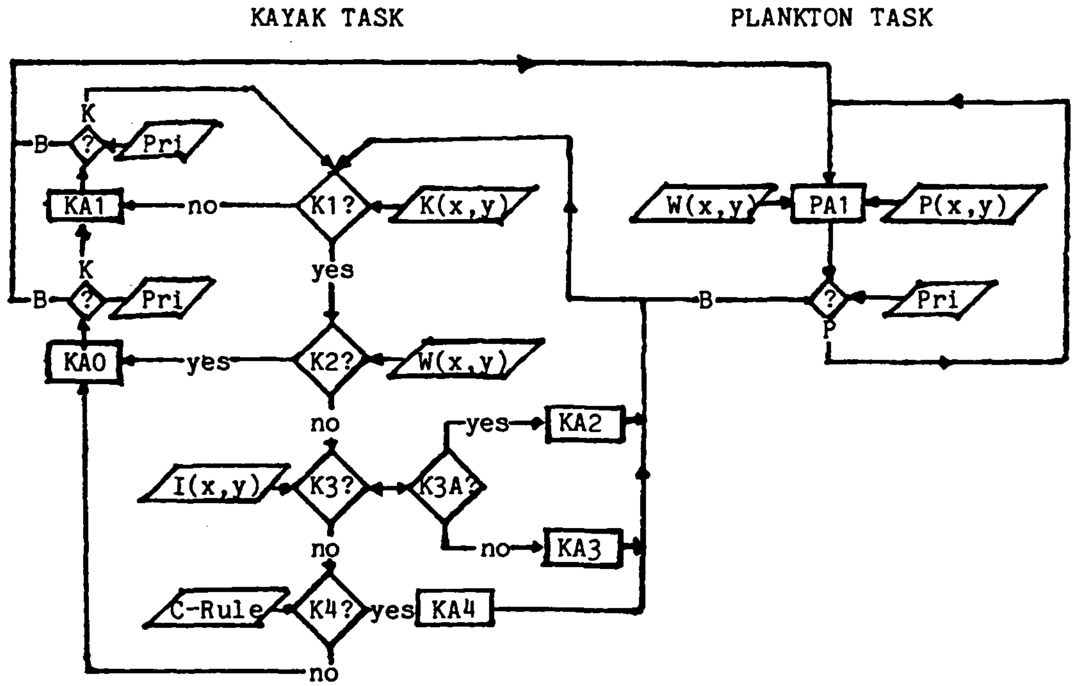
2:3c Logical Requirements

Another way to view the game is from the perspective of the logical operations necessary to perform the two tasks. A flow chart of these operations is depicted in Figure 2-3. Combining these operations with the constraint that inputs only occur once every three cycles (to approximate subjects' actual response rate - i.e., a directional change once every 2 seconds), this logic chart yields results which approximate subjects' performance. Although the higher complexity of the kayak task is already apparent, the logic depicted only deals with a single kayak. A diagram reflecting the logic necessary to explain the activities involved in simultaneously dealing with several kayaks would be much more complex.

2:4 OTHER INSTRUMENTS AND PROCEDURES

The context in which the game was played was also important. Several issues deserve comment. Despite the popularity of computer

LOGIC DIAGRAM FOR SAVE THE WHALE GAME



K - Questions:
- K1? - Is a kayak present?
- K2? - Is the kayak one space from the whale?
- K3? - Is an iceberg cluster directly between the kayak and whale?
- K3A?- Is the whale more than 2 spaces from the iceberg?
- K4? - Is the nearest iceberg fewer spaces (hzt or vrt) than the kayak (vrt or hzt)?

P - Actions:
- PA1 - Turn toward plankton.

K - Actions:
- KA0 - Ignore the kayak.
- KA1 - Turn toward the centre.
- KA2 - Turn toward the iceberg.
- KA3 - Turn away from the iceberg.
- KA4 - Turn toward a position to the iceberg but opposite the kayak.

K = Kayak   P = Plankton   I = Iceberg   W = Whale

Figure 2-3

games, they arouse anxiety in many individuals. Procedures adopted to decrease subjects' anxiety included: providing thorough explanations before each activity, introducing the game in incremental stages, giving subjects considerable latitude in determining the pace at which they worked through the schedule of activities and breaks. In short, an effort was made to put subjects at ease.

A separate issue involves individual differences and the choice of subjects. The age range of subjects for all experiments was between 18 and 38. The first experiment employed general subjects, but in an effort to reduce between-subject variance the second experiment employed only females. All later experiments used gender-balanced experimental designs with equal numbers of male and female subjects. It was clear from the outset that the level of performance varied directly with subjects' previous arcade experience and males on average had more such experience. Gender-balanced groups thus had had relatively similar ranges as well as average levels of arcade experience and consequently, game performance.

Subjects for all later experiments were students or the equivalent but were not all (or even predominantly) Oxford University students. The sample included many students from the local polytechnic or former "students" who had been out of school for several years. Despite the relatively small number of subjects involved with each experiment, the wide range of performance, provided the opportunity to explore cursorily individual differences.

After the schedule of events had been explained and subjects'

preliminary questions answered, the first task was presented. This was a four-choice reaction task. One of four whale symbols was presented in the centre of the screen, 500 msec later the plankton symbol appeared in one of the four cardinal locations next to the whale. Subjects were to tap the key corresponding to the plankton's relative location using the same controls discussed earlier. Correct responses were followed by a beep as the screen cleared. There was a one second pause between presentations.

In the first experiment 100 successive presentations were employed but only the fiftieth through the seventy-fifth were used to compute the average correct reaction time. For all subsequent experiments, two 75-presentation trials were included and all correct responses on the second trial were used to compute the average reaction time. Subjects were advised that if they were not making errors, they were not going fast enough, between the first and second trials.

Although the spatial mapping for the four-choice reaction task and whale control were the same, the type of control movement was rather different. While the reaction task elicited "ballistic" taps, whale control required a key to be pressed and held. This difference caused problems for a few subjects. Subjects received additional adaptive training in controlling the whale's movements from Experiment 2 onward. This task involved steering the whale around a single iceberg located in the centre of the screen. The whale's "control characteristics" were as close as possible to the game (i.e., the cycle speed and control lag). Subjects were required to complete 10 laps (involving 37 changes of direction) in under 70 seconds. Perfect performance would have resulted in total

time of approximately 50 seconds. Although some subjects met criteria on the first attempt, most required several attempts. All subjects, however, met the criteria by their ninth trial.

As mentioned previously, subjects were advised of the schedule at the beginning of the session and allowed to pace themselves between activities. For the game trials, subject's score sheets showed the total number of trials, when breaks would be taken, the experimental conditions (if any) and provided a space to record scores. The first two experiments were largely devoted to developing the game and appropriate supportive procedures and involved no experimental side tasks. The three later experiments involved verbal side tasks which were performed concurrently with the game. The specific side tasks will be explained in later chapters. In general, however, all experiments involved within-subject designs with every subject completing every condition and task priority combination. Order of presentation was counterbalanced across subjects.

Several measures were taken at the completion of the last game trial. These included a computer-generated set of questions to test incidental learning, an "espoused" strategies worksheet, comparative subjective rating scales for the three priority conditions and Witkin et al.'s (1971) Embedded Figures Test.

Twenty to twenty-five multiple choice and true-false questions were used to assess subjects' incidental learning after the last trial. The questions involved both detailed and global aspects of the game. Questions concerned graphic symbol identification (one for each of the component characters), basic operating characteristics of components, relationships between

components, situational (tactical) movement questions and general strategy questions. A full set of questions is provided in Appendix B.

It is difficult if not impossible to defend any specific set of verbal questions from the criticism that the "wrong" questions have been asked or asked in the wrong way. Unfortunately allowing subjects complete freedom to discuss their strategies in their own way often fails to provide the structure necessary for objective quantification and subsequent analysis (Nisbett and Wilson, 1977). The next instrument, the espoused strategies worksheet, was an attempt to give the subjects the maximum freedom to choose stategic explications within an objective framework.

Appendix C contains both the strategies worksheet (upper portion) and the priorities rating scales (lower portion). A two-step process was involved in working out the "espoused" strategies for each of the tasks. Subjects first judged whether or not activities contributed to the criteria. The activities were to be rated "+" if they contributed to performance, "-" if they interfered with performance or "0" if they were irrelevant to criterion achievement. Subjects then selected the two "most important" and marked them with an asterisk.

This procedure was followed first for the plankton task and then for the kayak task. The items came from two sources: 1) the verbal post-task explications of subjects from earlier experiments and 2) explicit translations of objective measures which could be taken and statistically compared to performance. Although it is impossible to overcome completely the wrong question criticism, this procedure seems a reasonable attempt.

Subjects also completed explicit ratings of the three priority conditions along three dimensions: difficulty, complexity, and uncertainty. Attachment 3 includes the instructions and the elaborative definitions for each. Subjects were verbally advised that their relative ranking of the three priorities was more important than the absolute values they assigned.

The final measure taken was the Embedded Figures Test (Witkin et al., 1971). This required subjects to find and trace simple figures "embedded" in 18 complex patterns. Performance on this task reflects subjects' "field independence" (the ability to break apart organized fields to identify targets). Field independence is associated with "high psychological differentiation" and correlates positively with other non-verbal intelligence measures. In contrast, "field dependence" (the inability to find the embedded figures) reflects susceptibility to environmental intrusions, a tendency toward "functional fixedness" and a preference for global rather than analytic processing. Noting that "field independence is extremely frequent among pilots," Mabry et al. (1980) found embedded figures test scores significantly moderated a number of other individual difference measures to predict tracking performance.

At the completion of all activities, subjects were paid and debriefed. All subjects had improved in their performance, which provided the experimenter the opportunity to focus on the positive aspects of their activities.

2:5 SUMMARY

A successful experiment has both the internal control necessary to yield significance results and is sufficiently and

substantively similar to the tasks in the external world it proports to represent. Many features of the general experimental procedure were directed toward preserving the "integrality" of the task while surreptitiously exerting necessary controls (Webb, Campbell, Schwartz & Sechrest, 1966). In many ways, games exemplify some of the best aspects of "enriched" jobs. Video games in particular offer unique opportunities to explore activities empirically which are both ecologically valid and psychologically interesting.

The particular game to be employed in the experiments which follow was incrementally developed within the constraints imposed by both internal and external considerations. SAVE THE WHALE involves two substantively different tasks: eating plankton and wrecking kayaks. These are combined in a dual-task paradigm with priority-induced performance shifts. Procedures were adopted to relax subjects and allow them to perform at their best. One aspect of computer games which makes them most attractive is their ability to make multiple objective measures of performance. These measures and the methods employed to analyse them will be presented next.

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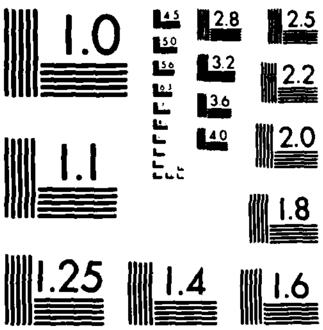


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

A FUNCTIONAL EXAMINATION OF INTERMEDIATE COGNITIVE PROCESSES

CHAPTER THREE

MEASUREMENT AND ANALYSIS

3:1 MEASUREMENT AND FUNCTIONALISM (Revisited)

A functional model of the information processing system was presented in the first chapter. This model provided a framework for developing experimental methods and procedures. The experiment itself is simply the occurrence of selected events in a partially-controlled situation of contrived conspicuity. This chapter discusses the measurement and analysis of such events. The particular objective is to glean objective, reliable and valid "system-critical" data. First measurement, then analysis will be discussed.

> The importance of the initial description in the study of behaviour has often been neglected ...a complex stream of behaviour must be described and broken down into units suitable for study. (Hinde, 1966, p. 9)

The validity of measures is of fundamental importance. The implicit assumption that easily obtained measures are the most psychologically important is a distressingly popular default. There are two approaches to establishing validity. These are, in turn, based on alternative philosophical theories of truth: coherence and correspondence. According to coherence theory, validity is the congruence of the supportive argument and its consistency with other accepted propositions. In contrast, correspondence theory suggests a measurement is valid if, and only if, it is directly reflected in reality (i.e., maps onto objective and observable relationships in the physical world). As Johnson-Laird (1983) suggests, there are disadvantages in the

exclusive reliance on either:

> correspondence ...exerts a dangerous pull in the direction of empirical pedantry, where the only things that count are facts, no matter how limited their purview ...the coherence of a set of assumptions ...exerts a dangerous pull in the direction of systematic delusion, where all that counts is internal consistency, no matter how remote from reality. Give up one approach and you turn into a Gradgrind, the teacher in Dicken's novel Hard Times, whose only concern is with facts; give up the other and you become an architect for the Flat Earth Society. (pp. xi-xii)

The tactic to be employed here is consistent with the strategy of this thesis. A global model (based on the functionalist conceptualization of hierarchical levels of control) will be presented. This will be used to suggest the types of measures which might explain performance in the SAVE THE WHALE computer game. This approach generates more measures than necessary. Post hoc statistical analyses is employed to select the measures which provide the most efficacious, elegant and parsimonious explanations. These selections can then be tested by replication. Thus, coherence criteria are used to generate alternatives and correspondence criteria to select and test those for which the empirical support is greatest.

Actions can be described at different levels as well as being of different types. As Mook (1982) points out: "the same act could be described as 'lowering the forearm', 'driving a nail', 'building a house', 'earning a living' and so on" (p. 63). Levels of description range from broad, general categories (i.e., the "molar level") to detailed descriptions of the temporal and physical aspects of particular motor activities (i.e., the "molecular level"). This distinction relates to one of functionalism's central tenets: the hierarchy of control.

One distinguishing characteristic of the functionalist approach was William James' (1980) view of the mind as the "master organ" of the body. The mind was seen as the superordinate of behaviour; intention was granted ascendancy over action. When Kenneth J.W. Craik resurrected functionalism in the 1940's, the concept of hierarchic control retained its position of prominence. In what has become a classic functionalist analogy, Craik (1966) illustrates the concept:

> For instance C.-in-C., Fighter Command, presumably says: 'We want a sweep carried out over such and such an area'; he does not have to add: 'This means Spitfire No. so-and-so on such and such a station must have so many gallons of petrol in its tanks and care must be taken that its plugs are clean and its guns loaded.' These latter details are delegated to subordinates. In just the same way, for rapidity and certainty in action, it is essential that certain units of activity ...be rapidly and certainly turned on and off at the command of the higher centres. (p. 38)

Broadbent (1971) formally proposed the existence of information processing mechanisms at two "levels". The upper mechanism was characterized as an active cognitive control system that monitored the operation of a relatively passive lower processing mechanism. Broadbent (1971) presents evidence that these mechanisms are affected by distinctly different factors. Noise, amphetamines, sleep loss and chloropromazine influence the activity of the lower mechanism. In contrast, task duration, time of day, alcohol and personality (i.e., introversion) primarily influence the upper mechanism. The fact that interactive effects on performance are more frequent when two arousers from the same group are present, corroborates this distinction. Recently, Broadbent (1984) reiterated the importance of such a differentiation:

> ...it is too simple to treat 'performance' as a single variable. One must distinguish the case in which people intend to do the right thing but fail, and the case in which they intend to do the wrong thing and succeed in the intention ...we have to regard human performance as made up of a number of separate functions. Conditions that cause disruption in one of these functions may leave others unaffected. (p. 5S)

Reason (1977, 1979, 1984) offers a similarly functionalist formulation. His composite model accounts for many important aspects of everyday behaviour including occasional absent-mindedness. Its principal components include intention, action and motor output systems. The intention system formulates plans and initiates actions. The action system assembles necessary subroutines commensurate with the activities initiated and exerts moment-to-moment control. An interesting feature of Reason's model is that the action system may independently drive the motor output function in an "open loop" mode of operation. Reason (1977) tacitly suggests the activities of the intention system are "evident in the contents of consciousness ...highly verbal and ...(of) limited capacity" (p.33). Independent action system control of behavioural output, therefore, implies automatic processesing.

Functional hierarchies often contain three conceptual levels although the distinctions between levels, however, seem to be as much a matter of theoretical convenience as compelling empirical evidence. Reason's (1977) three levels (i.e., intentions, action systems and the motor output system) will be adopted directly. Distinct functions are assigned to each level: global planning and formulating strategies to intentions, developing local plans or tactics to action systems and implementing or executing these

procedures to the motor output system.

This hierarchy is reflected by the questions each level addresses. Intentions concern questions at the highest conceptual level; "Which?" is a representative interrogative. Action systems are more locally oriented; "What?" and "Where?" are questions to which action systems provide answers. "How?" is the concern of the motor output system. Within the constraints provided by higher levels, the motor output system performs the task. Other characteristics differentiate these levels as well.

In searching for behavioural indicants of subjects' intentions during a particular task, several criteria are appropriate. Measures of intent should relate to the allocation of attention, effort, or resources. Intentional strategies should be global rather than local and generally accessible to verbal report. Although strategies are likely to emerge early in practice, they might be modified as subjects' skills improve.

Because tactics might involve either implicit or explicit knowledge, they are more difficult to define. While it is possible some tactical "rules" are verbal, subjects may not be able to state them. For example, in riding a bicycle, it is normal to turn left by first rotating the handle bars slightly to the right, then leaning left and returning the front wheel to its original orientation. Few cyclists realize this sequence takes place (in fact most are "certain" they initiate turns to the left by turning the handle bars to the left) and yet they consistently employ the appropriate rules. Unlike the bicycle turn, it is also possible certain "rules" contain knowledge which cannot even be verbally coded (e.g., when a skilled performer makes choices based on "the

way things seem"). As Rock (1983) suggests:

> to the extent that some or all of these rules do derive from experience... it is legitimate to consider them as a form of knowledge... the content (is) not conscious and the process of acquisition (is) not conscious either... (these rules) clearly are not in the form of a natural language... (but) they are represented symbolically in some form. (310-311)

Unlike strategy measures which are concerned with the allocation of resources to all aspects of the task, tactics relate to specific tasks but are relatively independent of others.

Measures which reflect the activity of the motor output system also have distinct characteristics (Summers, 1981). The motor output system can be employed by different action systems in performing various tasks. Whereas some rules can be explicit and logical, measures of the motor output system are likely to be nonsense if uncoupled from their tactical contexts. Psychophysical measures, reflecting the minutiae of subjects' responses are ideal indicants of the motor output system. The frequency or temporal infra-structure of output behaviour is at the correct level. Again the technique of measuring several alternatives then selecting those most useful will be employed.

3:2 MEASUREMENT OF SAVE THE WHALE VARIABLES

One great advantage of employing a computer game is the objective and automatic recording of many discrete events. The game itself constrained subjects' behaviours to a considerable degree. Once every cycle, subjects "chose" one of five mutually-exclusive responses (i.e., they pressed one of the four directional keys or made no input). However, to provide an appropriate context for these outputs, the discussion of measures must begin at the opposite (i.e., molar) end of the hierarchy.

In presenting these measures, a balance must be struck. Strong and apparently "a priori" logical arguments for several measures at different levels could be presented. This, however, would be inconsistent with the actual derivation of these measures. Dozens of measures were taken and literally hundreds of possible combinations were inspected using data from the first few experiments. To do justice to this process (if indeed such an intuitive activity can or should be justified) would require more time and space than the product warrants. As Fentress (1973) suggests "...categories of behavior must be formed but the investigator must not believe them!" What follows is a rationalization of the measures to be reported, a truncated story of how they were developed and a mention of several variables that proved to be much less useful or interesting than hoped.

Assuming subjects were committed to "playing the game", the most basic question involved which task to perform. The priority instructions and differential points were designed to induce shifts of intent. Determining to which task subjects were actually committed at any moment was very difficult. This was particularly true of the kayak task (some subjects did worst when it was obvious they were trying hardest). On the other hand, because the plankton task was so simple (i.e., salient), subjects' intentional commitment was clearly reflected by their general proximity to the plankton.

On each cycle the whale's location relative to the plankton (either zero, one, two, three or more spaces away) was recorded. Although the plankton moved randomly, its progress was relatively slow, often punctuated by pauses of several cycles. Thus, even the

least capable subjects could stay close to the plankton if they so intended. Because hierarchic indicants will be employed to predict criteria (i.e., plankton eaten), it is important that they be physically independent. Scoring events themselves were, therefore, excluded from the computation of all other measures. Although the most appropriate measure of intention (in terms of number of spaces) varied between subjects and even within subjects, the value of "less than three spaces" received convergent support from several aspects of the evidence (e.g., it was the average pivot point for subjects' frequency-distance profiles). The total number of cycles, in which the whale was within three spaces of the plankton (i.e., one, two or three spaces away) was adopted as the indicant of subjects' intention.

The strategic measure of intention reflects subjects' choices between the two tasks; task-specific action systems reflect "what" subjects did to accomplish each task. First, the plankton action system will be discussed. Again, the whale's position relative to the plankton was important. Intention alone was sufficient to bring the whale within three spaces of the plankton, but action-system skill was required to "make it eat". Therefore a measure of the whale's activity while close to the plankton, independent of the duration of its stay, was sought to provide an appropriate action-system indicant.

The relative frequency of one of the component events (the whale being one space from the plankton) was selected. Because of the "checkerboard phenomenon" discussed earlier, it was impossible for the whale to score during half the cycles. On these cycles, the whale could, however, often remain within one space and thus

be in position to score on the succeeding cycle, whereas turning in the wrong direction resulted in the whale being three spaces away. The proportion of one space cycles reflected the relative efficiency of performance within the plankton's vicinity and although correlated with both the intention measure and the criteria, was physically and conceptually independent. This measure was therefore, employed as an indicant of the plankton action system.

Unfortunately a clear measure of the activities involved in the kayak task was not available. If subjects were attempting to wreck kayaks when they were not near the plankton, many different measures were possible but none were obvious. These measures include absolute position, kayak movements and collateral events. Several of each type will be discussed.

The display contained four clusters of icebergs, one in each of the four quadrants. One measure involved simply counting the times the whale was in each of the four quadrants formed by bisecting the screen with horizontal and vertical lines through the centre. A more molar measure, derived by collapsing the four frequencies into a single dimension (contrasting a commitment to a "one quadrant" tactic to a "move around" tactic) proved a more useful predictor. This was accomplished by assigning one point for each of the four quadrants in which the whale spent less than 10 or more than 100 cycles. An additional point was assigned for each additional 25 cycles in a quadrant over the initial 100. Scores could range from 1 to 10. This measure proved more useful than either single quadrant measures or difference measures (which implied qualitative differences in the quadrants).

Another positional measure involved the relative amount of time the whale spent in the central area of the screen bounded by the four clusters of icebergs. Because this area overlapped all four quadrants it was physically independent of the multi- vs. single quadrant dimension.

Another type of measure reflected kayak movement and longevity. For each cycle a kayak was present, it moved in one of two ways: either one space horizontally or vertically or one space diagonally. Since the whale's movements determined the kayaks' movements, the kayaks provided an indirect indication of the whale's activity. If the whale was moving directly toward or away from a kayak, the kayak travelled horizontally or vertically (one space at a time). If the whale was moving orthogonally to the kayak's approach, the kayak moved diagonally (one space vertically and horizontally). A number of different combinations (i.e., differences, ratios and sums as well as simple frequencies of these two types of kayak movements were examined). The best measure was the simple frequency of kayaks' horizontal or vertical moves (i.e., line-up time). This measure was negatively related to criterion achievement. High values could be associated with a number of activities but were most directly and positively affected when subjects turned away from the kayaks.

Still other measures reflected the occurrence of collateral events. Since the whale could only avoid kayaks by getting them to crash into icebergs, reducing the number of icebergs seemed a rather foolhardy tactic. The number of icebergs decreased each time the whale swam through one. The number of icebergs "eaten" by the whale thus provided another interesting measure. Another

discrete and presumably undesirable event occurred when the whale was about to go off the screen; it simply bounced back one space. The plankton reversed direction one space short of the extreme border and the border location offered no protection from the kayaks. It was, therefore, assumed that the whales' time at the border was a bona fide blunder. Thus the frequency of "border blunders" was also recorded.

These last two measures were not significant predictors of performance on either task. After considerable analysis (i.e., groping and hoping) the unit-weighted sum of three rules was found to be a useful and relatively robust predictor of performance on the kayak task. These rules were: stay near the centre, stay in one quadrant and don't try to run away from the kayaks. This sum was employed as the indicant of the kayak action system.

The final level for which measures were taken was the motor output system. The most predictive measure at this level was the most simple: the number of times the whale actually changed direction. Measures of the temporal structure of inputs were also taken. Initially two measures were taken: those times when changes in the whale's direction of travel were initiated in the 150 msec before the computer read the keyboard and those inputs which were made in the 150 msec immediately after the keyboard was read. Again sums, differences and ratios were examined but the simple measure (the frequency of changes within the last 150 msec) proved the most interesting and reliable.

To summarize briefly, the whale's proximity to the plankton was assumed to indicate subjects' intention. The proportional frequency of cycles the whale was one space away from the plankton,

was proposed as a measure of the plankton action system. The kayak action system was represented by the unit-weighted sum of three rules: staying in one quadrant, staying in the central area and not trying to run away from the kayaks. The number of times the whale changed direction reflected the contribution of the motor output system. Methods for examining how these measures relate to each other as well as criteria will now be discussed.

3:3 CAUSALITY AND MULTIPLE REGRESSION ANALYSES

Each experiment yielded a great deal of data. Approximately 20 different performance measures were taken for each of the 15 to 27 trials the 20 to 24 subjects completed. Thus, data matrices contained 6,000 to 13,000 values. Additional data reflected subjects' performance of the non-game activities (e.g., the reaction task, Embedded Figures Test, incidental learning measure and the espoused strategies worksheet).

The need for data reduction was obvious. Problems involved in this step, however, are similar to those involved with measurement. Data reduction (i.e., representing the information these matrices contain by statistical descriptions) necessarily involves focussing on some aspects of the data at the expense of others. After the time and effort (both the subjects' and the researcher's) expended to generate so much information, the compulsion not to "throw anything away" was difficult to overcome.

Although the possibility of "missing" something relevant is a ubiquitous danger in data reduction, employing methods sensitive to the relation-structures embedded in these data minimizes the risk. On the other hand, over-analysis poses its own dangers. If 100 relations are inspected, finding half a dozen significant at the

.05 level is hardly surprising. Descriptive measures can provide useful augmentation for interpreting inferential statistics. Descriptive statistics go well beyond simple means and standard deviations and can include various measures of "effect size" (e.g., regression coefficients, proportions of variance explained and other correlational indices). These help shift emphasis from questions of "significance" to questions of "magnitude".

There are also instances, however, where inferential statistics (a method of rejecting null hypotheses on the basis of probability estimates) can be usefully employed. As Kenny (1979) points out, however:

> The term correlational inference should not be taken to mean various statistics are by themselves inferential. Regression coefficients, factor loadings and cross-lagged correlations do not, in and of themeselves, have an inferential quality. Given a plausible model, a statistic can be used for inferential purposes but the statistic itself is merely a passive tool. Inference goes on in the head of the researcher, not the bowels of the computer. (p. 2)

In this respect, convergent evidence from other statistical analyses within each experiment, replication of results by similar experiments or complementary findings from different experiments provide valuable support. All three sources (i.e, descriptive measures, inferential statistics and convergence) will be employed to help draw appropriate substantive inferences.

The development of the controlled experiment is largely responsible for the rapid progress of the natural sciences over the last three centuries. As discussed earlier, control is achieved by care and precision in manipulating experimental conditions and by isolating other possible influences. The virtue of the experiment lies in the simplicity of its underlying causal model (i.e., X

causes Y). Although this model and relatively simple statistical analyses are sufficient when such control is employed, they become less adequate as the simplifying constraints are relaxed and subjects are afforded greater discretion. In these cases, theories must be developed from passive observation where behavioural phenomena are more variable, putative causes more obscure and effects more subtle.

Path analysis provides an alternative approach. Originated by Wright (1921) for applications to genetics research, this methodology was quickly adopted by other social sciences. Path analysis provides an internally coherent approach for the quantitative analysis and testing of theories by data derived from the observation of naturally occurring events. Perhaps one of the clearest and most comprehensive treatments of causal analysis and its major analytic tool, multiple regression, is provided by Cohen and Cohen (1983):

> The basic strategy of the analysis of causal models is first to state a theory ...explicitly ...what causes what and what does not, usually aided by causal diagrams. The observational data are employed to determine whether the causal model is consistent with them, and estimate the *strength* of causal parameters. Failure of the model to fit the data results in falsification, while a good fit allows the model to survive, but not be proven, since other models might provide equal or better fits. (p. 14)

Further elaboration of this approach reveals the close correspondence between path analysis and multiple regression. Kenny (1979) identifies "causal laws" of the form "For all Q, X causes Y" as the building blocks of path analyses. In this instance, Q is the target population, X is the exogenous variable or cause and Y is the endogenous variable or effect. Since both cause and effect are variables, the relationship between them can

be expressed in the form "$Y = b_o + b_a X$". The term b_a is the causal parameter which reflects the magnitude of the effect of X on Y. If X is increased by one unit, Y will increase by b_a units (i.e., b_a represents the slope of the linear function relating the two variables and b_o the intecept).

Instead of just one cause, an effect may be influenced by several variables. A simple additive relationship of this kind would be of the form

$$Y = b_o + b_a X_a + b_b X_b + b_c X_c \cdots + b_n X_n$$

In this case the value of each causal variable (X_n) is multiplied by its causal parameter (b_n). Whether a particular variable is endogenous or exogenous is not an inherent characteristic but reflects the nature of the overall relation structure. A particular variable may well be both exogenous (i.e., a cause) to some variables and endogenous (i.e., an effect) to others.

Kenny (1979) suggests that X is a cause of Y if: X precedes Y in time, there is a demonstrable relationship between the two (i.e., a correlation) and this relationship is not spurious (i.e., caused by a third variable exogenous to both). Causal relations between variables can be represented graphically as paths (directional arrows emanating from causes and terminating in effects). Standardized regression coefficients, betas, are listed as path weights. Reciprocal exogenous relations (i.e., non-causal ones) are represented as curved double-headed arrows with the path weight computed in the same way but are devoid of causal implications.

The portion of a criterion's total variance explained by exogenous variables is reflected by R^2. The remaining variance

(the disturbance or residual error) is represented as a separate exogenous variable. The independence of these residuals for different variables is a fundamental assumption of causal models. A relationship between residuals shows that an important exogenous variable was not specified by the model; this is shown by patterns in the plots of residual values (Nie et al., 1975).

There are two types of common relationships which cause simple linear regression equations to underestimate the magnitude of relationships between variables: curvilinear relations and interactions. Cohen and Cohen (1983) provide comprehensive explanations and remedies for both problems. Many curvilinear relations can be adequately represented by the inclusion of a single additional exponential term (i.e. X^2). Likewise, the presence and effects of interactions are reflected by an additional discrete regression coefficient (i.e., the product of the interacting variables) if, and only if, the primary variables have been entered in the equation. Cohen and Cohen (1983) point out that because these non-linear characteristics "under-estimate" the effects of exogenous variables, they obscure rather than confound the results.

3:4 SPECIFIC ANALYSES OF GAME PERFORMANCE DATA

Even with as powerful a tool as path analysis and a data analytic system as flexible and robust as multiple regression, large data matrices present problems. For well-established experimental paradigms or frequently-observed behavioural phenomena, a single type of analysis is often adequate. However, by selecting a paradigm lying between traditional experimental and purely observational research, one must forego such comforting

simplicity.

There are several interesting perspectives from which data might be examined. The global structure of the game itself, as reflected by the covariance of all measured variables, is intriguing. Total variance, however, is influenced by two distinctly different sources: the differences between subjects (i.e., individual differences) and the differences which occur within subjects (i.e., the common effects of practice, priority instructions or verbal side tasks). Because of the novelty of the research effort, analyses from each perspective will be performed. These will now be discussed in greater detail.

3:5 TASK STRUCTURE - GLOBAL ANALYSES

Analysis at the global level is directed toward describing the number and nature of the relations between the measures proposed earlier. To recapitulate, four exogenous variables, some of which were derived from several other variables, were proposed to explain two endogenous variables (viz., the criteria: plankton eaten (P) and kayaks crashed (K)). The proportion of the time the whale spent within three spaces of the plankton represented subjects' intentions (I). Two separate subordinate and specific action systems were also proposed. For the plankton task, the proportion of time the whale was one space from the plankton was proposed as a measure of the plankton action system (Ap). For the kayak task, the unit-weighted sum of variables reflecting subjects' adherence to three rules (stay in the centre, stay near one cluster of icebergs and don't turn away from the kayaks) was the suggested indicant of the kayak action system (Ak). The total number of times subjects changed the direction of their whales'

travel was proposed as a measure of the motor output system (M). The verbal descriptions of the hierarchic relations discussed earlier translate into the specific equations required for path analysis:

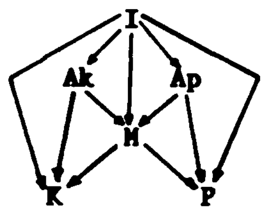
$$K = b_1 I + b_2 Ak + b_3 M + b_4$$

$$P = b_5 I + b_6 Ap + b_7 M + b_8$$

$$M = b_9 I + b_{10} Ak + b_{11} Ap + b_{12}$$

$$Ak = b_{13} I + b_{14}$$

$$Ap = b_{15} I + b_{16}$$



These equations are combined and presented graphically as the path model shown above. Because the number of paths specified (11) is less than the number of possible correlations (15) between the variables, the model is appropriately "overidentified." This is a necessary but not sufficient condition for accepting a model. (Underidentified models cannot be tested (Kenny, 1979).)

Because the direction of influence cannot be established absolutely, these procedures will not produce a true "causal model." However, the rigorous application of path analytic procedures will be employed to construct an objective representation of the relation structures which underly the task. The paths "not represented" by the model provide an opportunity to disconfirm the model. For example, if Ak affected Ap or P; or Ap affected K; or K affected P to a large degree, this would indicate either the model or the measures were inappropriate. Likewise, the presence of curvilinear relations or interactions would suggest the need for model modifications.

Causal modeling or path analysis provides a framework for inspecting the statistical consequences of the researchers'

explicit assumptions. These analyses necessarily involve two assumptions: 1) the measures are true indicants of the concepts they purport to reflect and 2) the concepts fit together in the manner specified. This is a messy but unavoidable characteristic of the initiation of inquiry.

3:6 ANALYSIS OF BETWEEN-SUBJECT VARIANCE

Several activities other than the computer game occurred during most experiments. Some of these yielded useful measures of individual differences. Two measures (viz., average correct reaction time and the embedded figures test score) reflect relatively stable and enduring individual "traits". These are assumed to be mutually exogenous (i.e., non-causally related). The measure of incidental learning was developed to tap the internal representations subjects gained from playing the game. The quality and nature of such representations could be influenced by both pre-existing traits and game events. By incorporating both verbal and nonverbal material, the incidental learning measure purported to reflect both implicit and explicit aspects. The strategies work sheet forced subjects to convert implicit knowledge into explicit rejection or acceptance of verbal rules.

If one assumes each of these variables is exogenous to performance, regression analysis is possible. This assumption is obvious for the trait measures; it is more problematic for the incidental learning and espoused strategy scores. Performing the task and gaining an internal model of its relation-structure might be so thoroughly intertwined, one could not be posited as more "causal" than the other. A possible argument to the contrary, however, follows:

Asymmetrical effects reflect causal relations. Observational learning (i.e., the acquisition of an internal representation without overt performance) is a common phenomenon (Bandura, 1977). The opposite effect (i.e., improvememt in performance without representation acquisition) is extremely rare (Adams, 1971). It was argued earlier, in fact, that an improvement in performance was sufficient to imply the presence of an internal representation even though subjects had no verbal access to such representations. If knowledge of results at all levels is withheld from subjects, no internal representations could be formed and performance would not improve. This hypothetical argument suggests incidental learning and espoused verbal strategies are exogenous to performance.

The performance variables themselves warrant consideration. The between-subjects variance is reflected by subjects' average scores on each variable. Each subject completed an equal number of trials in three priority conditions (i.e., plankton, equal or kayak priority). Although in the case of the motor output system, averaging across all these conditions yields an interpretable comprehensive measure, this procedure is less appropriate for the other measures. The clearest measure of subjects' ability to "eat plankton" is derived from plankton priority trials. Combining plankton performance scores under all priority conditions only obscures the data. Each priority condition had distinctive criteria: tonnes of plankton eaten, number of kayaks crashed and points scored for the equal priority condition. Average scores for these measures were derived from subjects' performance across all trials in each of the respective priority conditions. This same argument also applies at the action system level; scores for these

measures were likewise taken from only trials of the appropriate priority.

Again raw and percentage means and standard deviations for each of the measures will be presented initially. The effects of individual differences will be assessed by using correlation matrices then regression analysis. In addition to providing descriptive information, inferential analyses will also be presented concerning the significance of these individual differences on the performance measures.

3:7 WITHIN-SUBJECTS ANALYSIS

The portion of the variance not reflected by between-subject variance is within-subjects variance. Cohen and Cohen (1983) present an extensive explanation of the application of multiple regression analyses to repeated-measures designs. General multiple regression programs appropriately compute certain parameters (i.e., the proportion of variance explained (R^2) and unstandardized regression coefficients (B_n)). However, the program's contains incorrect assumptions concerning the appropriate degrees of freedom. This leads to all standardized and inferential measures being inaccurate. These problems can, however, be rectified by a few supplementary calculations.

Briefly, the computer falsely assumes each set of observations from a single trial is independent from all others, and thus misrepresents the degrees of freedom (i.e., does not adjust for the fact that trials performed by the same subject are not independent). Thus, the computer assumes the numerator to be simply the number of independent variables contained in the regression equation and the denominator, the total number of

observations less the number of independent variables less one.

The appropriate degrees of freedom for the numerator are the product of the number of independent variables and the number of observations (i.e., trials) per subject. For the denominator, the product of the number of observations and (the number of subjects less the number of independent variables less one) provides the correct value. The F statistic for the significance of the regression equation as a whole can be computed from the R^2 provided and corrected degrees of freedoms. The standard error for each predictor is thus underestimated by the quotient of the square root of the old (incorrect) degrees of freedom (for the denominator) divided by the square root of the adjusted degrees of freedom. Since the t statistic for each independent variable is the quotient of the unstandardized regression coefficient (which was correct all along) divided by its (corrected) standard error, the statistic can be easily computed. These procedures sound more complicated than they are. Cohen and Cohen (1983) present a complete explanation of the more general subject by conditions design.

There are several ways to approach within-subject variance. Each subject could be treated as a nominally-coded variable and the between-subject differences partialled out. This is an extremely inefficient method. Cohen and Cohen (1983) recommend breaking the analysis in two by separating between-subject and within-subject variance and treating them separately. This has already been done in the analysis of between-subject data. Standardizing scores by subject is one way to separate the within-subject variance by eliminating the between subject variance. The procedure for doing this is simple: the mean and standard deviation for each subject on

each performance measure is computed. Each individual score is then subtracted from the subject's mean and the difference is divided by the standard deviation of the subject's scores under all conditions. Cohen and Cohen (1983) list three properties of standardized scores:

> 1. The sum of a set of z scores and therefore also the mean equal 0.
> 2. The variance of a set of z scores equals 1.0, as does the standard deviation.
> 3. Neither the shape of the distribution of X nor its absolute correlation is affected by transforming it to z score. (p. 34)

Standardization by subject has several beneficial effects. Standardizing equalizes the variance contributed by each subject (this makes by-subject standardization an inappropriate procedure for between-groups or mixed designs). For repeated measures designs, however, standardization provides protection from the undue influence of outliers and minimizes the effects of individual differences. It is ironic that subjects with the greatest variance (sometimes the worst subjects) have disproportionately large effects on relational descriptions. Standardization forecloses this influence: the effect of each subject's performance is the same.

There is another attractive characteristic of within-subject standardization: it provides a common metric for comparing different tasks and different levels within the same task. Data thus reflect relative rather than absolute information. The effects of priority instructions, practice and experimental conditions can be directly compared. All measures are converted to the same terms: each subject's relative performance.

Standardization of scores is not a widely employed explicit

transformation, although many statistical procedures are, in fact, based on internally-standardized scores (i.e., multiple regression and factor analysis in particular). Kenny (1979) lists several criticisms of standardization: difficulty in cross-cultural generalizations, loss of interpretability, and unresolved statistical complexities. Although true, the first criticism is not immediately relevant to this thesis. The question of interpretability is interesting. If the raw metric has strong semantic connections, the process of standardizing scores makes the data more remote by severing those connections. However, for situation-specific metrics, such as those generated by the computer game, there is little to lose in terms of interpretability and a great deal to be gained by adopting common terms. As to the last question, Kenny's (1979) response is clearly applicable:

> ...standardized coefficients imply dividing by a sample estimate, the standard deviation. This should increase confidence intervals and alter tests of significance. Although these problems are beyond the scope of this text and the competence of its author, we should recognize that we created a statistical problem by standardization. We leave it to the statisticians to develop solutions to these problems." (p. 217)

In light of the foregoing, inferential statistics will be computed and presented, but will be treated with due caution. Even within these limitations, however, dealing with standardized scores remains the most attractive option.

3:8 SUMMARY

This chapter began with a discussion of the importance of measurement. The functionalist notion of control hierarchies was discussed then applied to the development of a range of performance measures. Causal modeling (i.e., path analyses) and multiple

regression were then discussed. Next these general concepts were incorporated into a specific plan involving three separate analyses.

The first analysis occurs at the general level and is directed toward developing a representation of the task structure and the relations between measured variables and criteria. This analysis employs multiple regression to define a path structure. The resultant structure provides a contextual frame for the variables it contains. Regression analysis will also be employed to investigate individual differences. The final analysis is perhaps the most important, however. It concerns the effects of priority instructions, practice and the experimental manipulations on subjects' performance. Within-subjects variance is separated from total variance by standardizing each set of scores by subject. This procedure equalizes subjects' influence on analyses and also provides an interpretable common metric for comparing performance of the two tasks at several levels. At last, the focus can be shifted to the experimental work itself.

A FUNCTIONAL EXAMINATION OF INTERMEDIATE COGNITIVE PROCESSES

CHAPTER FOUR

EXPERIMENT ONE - INITIATION OF INQUIRY

4:1 INTRODUCTION

Experiments One and Two served as pilots for those that followed. Their purpose was to help compensate for the lack of pertinent literature. Important questions at all levels required answers before substantive issues involving functional characteristics of the information processing system could be addressed.

One fundamental question concerned the equipment itself. In an age where it is common to work with apparatus valued substantially beyond most annual salaries, it seemed somewhat ambitious to attack psychology's most intractable problems - those involving differential strategies and behavioural integrality - with an inexpensive micro-computer and a patchwork game. Both the sensitivity and reliability of the equipment was undemonstrated. In contrast to the widely-accepted microsecond standard, most microcomputers provide timing estimates to the nearest fiftieth of a second. Some aspects of microcomputer operation (viz., loading and saving program information) are particularly susceptible to breakdown.

There were also questions concerning the appropriate number and type of subjects. While it is assumed general video game experience enhances playing ability and known that males have considerably more arcade experience than females, the empirical implications of these differences were less than clear. Performance variance caused by individual differences in experience

might be so great it would mask other effects. The desire to employ subjects from a broad sector of the population had to be tempered by the ability to derive meaningful information from the experiment. "Having fun" is a ubiquitous activity outside the psychological laboratory but if the particular activity cannot be "unpacked" reliably and objectively, it is of little empirical value.

Most studies involving computer games implicitly assume a single global measure of performance is adequate. In contrast, the importance of viewing performance as a multivariate phenomenon has become a major theme in contemporary experimental psychology (e.g., see Eysenck, 1982 or Broadbent, 1984). It is ironic that although computer games offer unparalleled opportunities for unobtrusively taking multiple objective measures, these opportunities have consistently been ignored by researchers.

Arguments were presented earlier for various measures and a hierarchic structure relating them to performance. One of the difficulties in investigating such a scheme is its isotropic nature. The function of any specific measure, and thus the validity with which it represents a particular concept, depends on the structure of the game and subjects' strategies. The validity of neither the measures nor the relation-structure can be assumed a priori. Negative or contradictory findings might reflect inadequacies in either or both. There is no way to completely resolve this difficulty. However, by making gradual changes and carefully observing their effects from a variety of perspectives, progress can be made in developing both models and measures of greater coherence and correspondence. The multiple analyses

described earlier are one way to work systematically toward these goals.

4:2 METHODS

General methods were discussed extensively in Chapter Two. This section identifies those aspects of Experiment One which diverged from the earlier discussion. Since this was the initial experiment, there were several substantial differences.

Ten male and ten female subjects between the ages of 18 and 38 were randomly selected from the Oxford Subject Panel. The panel consists of approximately 400 paid-volunteers who have agreed to serve as subjects for psychological experiments conducted under the auspices of the the Department of Experimental Psychology, Oxford University. Efforts are made to recruit widely from all levels and sectors of the local community (i.e., age, gender and level of education). However, because all members are volunteers, availible during the day and accept a relatively low rate of compensation (presently one pound fifty per hour), some sample characteristics are non-representative of the general population (viz., few fully-employed adults are panel members).

The apparatus employed for this experiment differed from subsequent experiments in several ways. Most noticeably, the game was displayed on a monochromatic, 13-inch Deccavision portable television. Also a tape recorder was used to "load" the program for each activity. This process required several minutes and occasionally malfunctioned. Subjects sat 36 inches from the television, video brightness and contrast were adjusted for the comfort of each subject and all activities were conducted in a moderately-sized, well-lit room.

The differences in the game will be presented in a bottom-up sequence starting with the control characteristics and ending with general procedures and presentation schedules. The game was relatively slow, with an average cycle time of 764 msec. More important differences from subsequent experiments emerge when this average time is decomposed into its components. The first is the minimum time between a subject's input (i.e., keypress) and the computer's response (i.e., printing the whale in a new location). The second component, additional required computation time, reflects the duration of other computer processes accomplished during each cycle. The third component reflects the extra time required for moving each kayak present during the cycle.

The values of these components were as follows: minimum lag - 360 msec, other fixed computations - 310 msec and increment per kayak - 80 msec. Compared to later versions, the minimum lag is much longer and the time for other computations much shorter. This meant subjects' control was less direct and the time available to make directional decisions was reduced.

An explanation of the sequence of events during a typical cycle illustrates the point. The whale's new location (and direction) and the plankton's new location were presented virtually at the same time (within the last 20 msec of the "minimum lag" time). If no kayaks were present, subjects then had 310 msec before the computer read the keyboard to determine where to print the whale to start the next cycle. If one kayak was present, the time increased to 390 msec and 470 msec if two were present. The computer "read" the keyboard and 360 msec later printed the whale and plankton in new locations. In comparison with later game

control systems, this one was noticeably more awkward.

The game consisted of 251 cycles and lasted 3 minutes, 12 seconds. There were three priority conditions. Unlike later experiments, there were also trials in which only one of the tasks was presented (symbols for the other task were suppressed). Also unlike subsequent experiments, unique constellations of between 16 and 18 icebergs and separate schedules for generating the kayaks were associated with each priority condition. The purpose of this variability was to prevent subjects from getting bored or learning a single optimal set of moves. (Subsequent analyses provided little justification for either concern.)

Two other differences involved the kayak task specifically. Subjects gained points each time a kayak crashed into an iceberg, but did not lose points when a kayak reached (and harpooned) the whale. In fact, getting harpooned was not even marked acoustically. The only cost of being harpooned was the lost opportunity of gaining points by making the kayak crash. There is no logical difference in the two scoring systems (harpooning and crashing were exhaustive and mutually exclusive outcomes), but the psychological difference might be important.

Additionally, the following message was appended to the pregame instructions:

> "One final note: Please don't eat the icebergs - (this makes the eskimoes task much simpler and yours much harder)."

Also no direct measurement of kayak movement (i.e., whether horizontal, vertical or diagonal) was made. However, this value was estimated from available measures (i.e., the proportion of kayaks moving diagonally when they crashed, the number of kayaks

launched and the number of cycles each was present).

There were also deviations from the general procedures outlined earlier. Subjects completed a single 100-trial, four-choice reaction task before beginning the game. While this familiarized subjects with the spatial mapping between control keys and the whale's direction of movement, temporal characteristics remained obscure.

All subjects completed 17 trials of the game. The first trial involved the plankton task alone and the next two involved only kayaks. Half the subjects then completed 12 dual-task trials with designated priority shifting from kayaks to equal to plankton on each successive trial. The other subjects completed these trials in the reverse rotational order. The last two trials were again the same for all subjects: the penultimate being plankton alone and the final, kayaks alone.

Subjects were given 25 computer-presented questions as an indicant of incidental learning. The other measures of individual differences (i.e., Espoused Strategies Worksheet and Embedded Figures Test) were not administered. Total time for the experiment was approximately two hours.

4:3 RESULTS

Data were analysed from three separate but convergent perspectives. First, raw data were inspected to determine the games' "relation-structure". Next subjects' average scores for selected variables were compared to discern the effects of individual differences. Finally, within-subject analyses were conducted by standardizing scores for each individual and examining the relative effects of practice and priority. Results from each

will be presented sequentially.

4:3a GLOBAL ANALYSES

Raw data are described in three ways. Means and standard deviations for the hierarchic performance measures and criteria provide general information. Zero-order linear correlations (r) show the relationships between these measures and provide the basis for understanding the task's "structure". However, a fuller appreciation of the task structure is gained by combining correlational information with the hierarchic assumptions presented in Chapter Three.

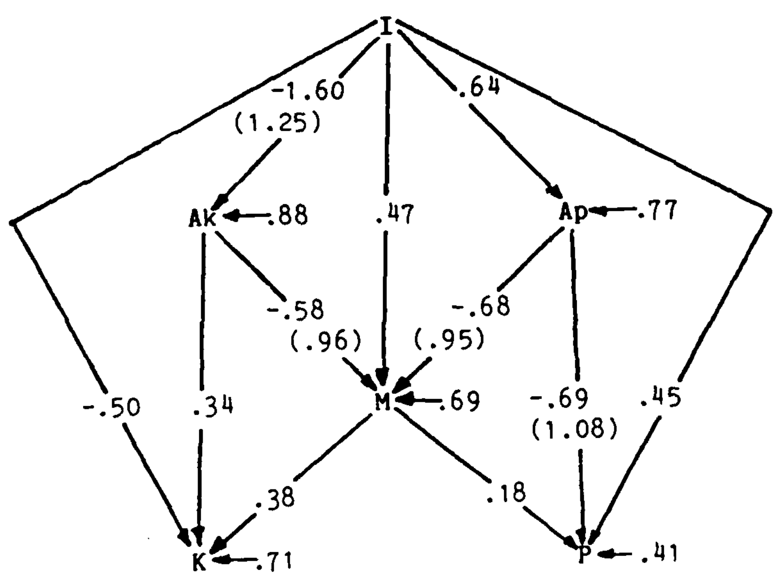
Descriptive statistics, the correlation matrix and task structure are presented in Figure 4-1. The measure of intent (being within three spaces of the plankton) shows subjects' whales were near the plankton 31 percent of the time (35 percent if the number of times they scored on the plankton is included). It is important to note this measure of intention is constrained to positive numbers; the distribution is "cut off" at a point 1.5 standard deviations below the mean (i.e., zero), creating a positive skew. Although normally distributed variables are best suited for subsequent analyses, Cohen and Cohen (1983) argue deviations from normality only diminish the strength of relational descriptions and thus introduce a conservative bias. The conceptual and technical difficulties involved in "normalizing" data or using log-linear transformations render these treatments inappropriate for exploratory studies such as this one.

The measure of the kayak action system is simply a unit-weighted combination of the "rules" found to be associated

DESCRIPTIVE STATISTICS, ZERO-ORDER CORRELATIONS
AND TASK STRUCTURE FOR EXPERIMENT ONE*

Variables**	I	Ak	Ap	M	P	K	IBE	CEN	LUT	QST
Mean	79.2	5.11	.294	63.9	9.0	10.2	1.87	106.0	58.2	1.13
SD	53.8	1.71	.104	15.8	8.8	3.7	1.78	36.5	51.9	1.91
I		-.28	.53	.50	.75	-.28	.03	-.10	.42	-.51
Ak			-.24	.15	-.25	.55	.01	.57	-.58	.55
Ap				.35	.66	-.20	.10	-.03	.02	-.41
M					.64	.31	.06	.14	.02	.01
P						-.27	.19	.07	.23	-.38
K							-.10	.20	-.29	.42
IBE								.27	.12	-.09
Cen									-.04	-.06
LUT										-.21

TASK STRUCTURE



* N= 340 (20 subjects X 17 trials)

**Variables: I= Intentions (less than three spaces); Ak= Kayak Action System (centre, not lined-up, one quadrant); Ap= Plankton Action System (one space percentage); M= Motor Output System (changes of direction); P= Plankton eaten; K= Kayaks destroyed; IBE= Icebergs eaten; LUT= Line-up time; QST= Commitment to one quadrant strategy.

Figure 4-1

with crashing kayaks (Dawes, 1982). These rules are: stay in the central region, stay near one cluster of icebergs and avoid turning away from or lining up with the kayaks. Average values for these rules are shown in the last three columns. As mentioned previously, line-up time (LUT) was estimated from other available measures. The quadrant strength measure is skewed; however, combining it with two normally distributed variables attenuated the skew and the combined variable (Ak) is normally distributed. Another potential rule (viz., don't eat icebergs) is reflected by the number of icebergs subjects destroyed during each trial (IBE). In comparison to later experiments, the average (1.87) is low, showing the effect of the pre-game "hint".

The measure of the plankton action system (Ap) also warrants explanation. Considering all of the times (i.e., cycles) the whale was within three spaces of the plankton, the action system indicant is the proportion of the time the whale was one space from the plankton. It is a measure of average efficiency. As a result of the checker-board effect, it was possible for the whale to score on plankton on only about half the cycles (i.e, during those cycles on which the plankton was located on the same "type" of space the whale was moving into). The plankton action system indicant reflects performance during cycles in which the whale could not score (e.g., the whale was moving to a "dark" space and the plankton was located on a "light" space). Thus, the proportion of "one-space-away" cycles is conceptually distinguishable from the measure of intent and structurally independent of criterion achievement.

The indicant of the motor output system (M), is the number of

times subjects changed the whale's direction. The raw score of 63.9 implies subjects made effective inputs only about once every 4 cycles (i.e., 3 seconds). Further analysis revealed that on 64 percent of the other cycles, subjects were, in fact, unnecessarily pressing the key corresponding to the direction the whale was already travelling.

Performance on the two criteria, plankton-eating (P) and kayak-crashing (K) are reflected in the next two columns. Again considering the "checker-board effect," the overall 9.0 tonne average implies subjects were performing at about 8 percent of optimal. Average performance on the kayak task was represented by crashing 10.2 of the 25 kayaks generated for each trial (i.e., a little over 40 percent of optimal). Performance of both tasks was well below "ceiling" and concerns about subjects' learning single solutions evaporated after observing the struggles of the first few players.

The next portion of Figure 4-1 presents a correlation matrix reflecting the linear relationships amongst the variables. A few points are noteworthy. Intention (I), the plankton action system (Ap), number of directional changes (M) and plankton eaten (P) are all intercorrelated ($.35<r<.75$). Although there are no measures with singularly strong correlations with kayak crashing, the composite estimate of the kayak action system (Ak) shows a relatively strong relationship ($r=.55$). Contrary to the suggestion in the "hint," the number of icebergs eaten is unrelated to most other measures.

A model of the task's structure-relations was derived by superimposing these raw data on the logical hierarchy. The

multiple regressions on which this model is based were accomplished in the following manner. For each lower-level variable all appropriate higher-level variables were entered into the regression equation. Next, the question of non-linear relationships was adressed by inspecting the "entry charactaristics" of variables reflecting curvilinear aspects of each path (i.e., variables created by squaring the value of each higher-order measure (Cohen and Cohen, Chapter 6, 1983)).

Two types of criteria were employed to determine whether to include additional influences. The first of these incorporated the standard F test which reflects the contribution each exogenous variable makes to the overall explanation of the variance in the endogenous variable. Although this statistic (and its square root, t) is grossly overestimated due to the inappropriate assumptions the statistical program contains concerning the degrees of freeedom, it provides a common, objective entry criterion. Consequently, an arbitrary entry t value of 5.00 was selected.

The second criterion concerns the variable's "tolerance." This value represents the portion of the variance in the potential predictor variable not explained by independent variables already in the equation (Nie et al., 1975). Because of the exploratory nature of this study, the tolerance criteria was set at a conservative value of .05. Variables in which over 95 percent of the variance was explained by variables already in the model were not entered. This helped guard against incorporating redundant explanations thereby avoiding the destabilizing effects of multicolinearity. Multiple alternative explanations for a phenomenon might be interesting but are not conducive to developing

parsimonious models.

After entering all predicted paths and inspecting potential curvilinear aspects, effects of interactions between included variables (Cohen and Cohen, Chapter 8, 1983) and non-predicted paths were inspected. Variables meeting inclusion criteria were incorporated in the model. Finally, each of the predicted paths was reinspected with respect to the "computed t" criteria; predicted paths failing this criterion were depicted as broken lines.

Several conventions were adopted for the presentation of the task relation-structure. The number immediately to the right of each of the endogenous variables is the error term. Its square is the portion of the variance not explained by the depicted paths. The path coefficients themselves are standardized partial-regression coefficients (i.e., betas). Nie et al. (1975) recommend:

> if one is interested in the relative amount of variance explained by independent variables, the standardized coefficients are appropriate. If the independent variables are measured in different units and the main interest is in assessing the overall effect of one variable over another ...the standardized coefficients will be more intelligible. (p.397)

In the analyses of these data, several paths were found to be better described by curved rather than linear relationships. These are depicted by the inclusion of two weights along the path. The first of these reflects the linear constituent of the relationship and is orthogonal to the axis of the quadratic curve. The second beta (shown in parentheses below the first) reflects the degree of curvature. In combination these two components can describe many different curves. The four indicated curvilinear relationships

have been plotted in Figure 4-2.

This lengthy introduction allows only a few comments concerning the model itself. The model explains achievement of the two criteria well. About 50 percent of the variance in kayak crashing and 83 percent of plankton-eating is predicted by the prescribed combinations of three exogenous variables. Because the kayak action system measure (Ak) is only an estimate of a variable found to be useful in subsequent experiments, the two curved relationships it involves might be artifacts of the estimation computation.

The symmetry of the curves showing the influences of the two action systems (i.e., Figures 4-2 b and 4-2 c) on the motor output system is noteworthy. The troughs near the means of these respective predictors have interesting implications. Trials not marked by clear commitments to either task (i.e., moderately low scores on both action system indicants) involved relatively few changes of direction. This suggests a positive relationship between "knowing" what to do (either implicitly or explicitly), and high levels of activity. Additionally, there was a bias toward greater activity when subjects intended to perform the plankton task. This is shown by the positive linear influence of intention on the motor output system. These influences accounted for 52 percent of the variance in the motor output system.

The curvilinear relation between the plankton action system and tonnes of plankton eaten is also interesting. It is important to consider all depicted paths when interpreting each influence. Superficially the curve depicted in Figure 4-2d suggests that as players improved efficiency from low levels (i.e., from -1.0 to -.5

DEPICTION OF CURVES INDICATED
IN EXPERIMENT ONE TASK STRUCTURE

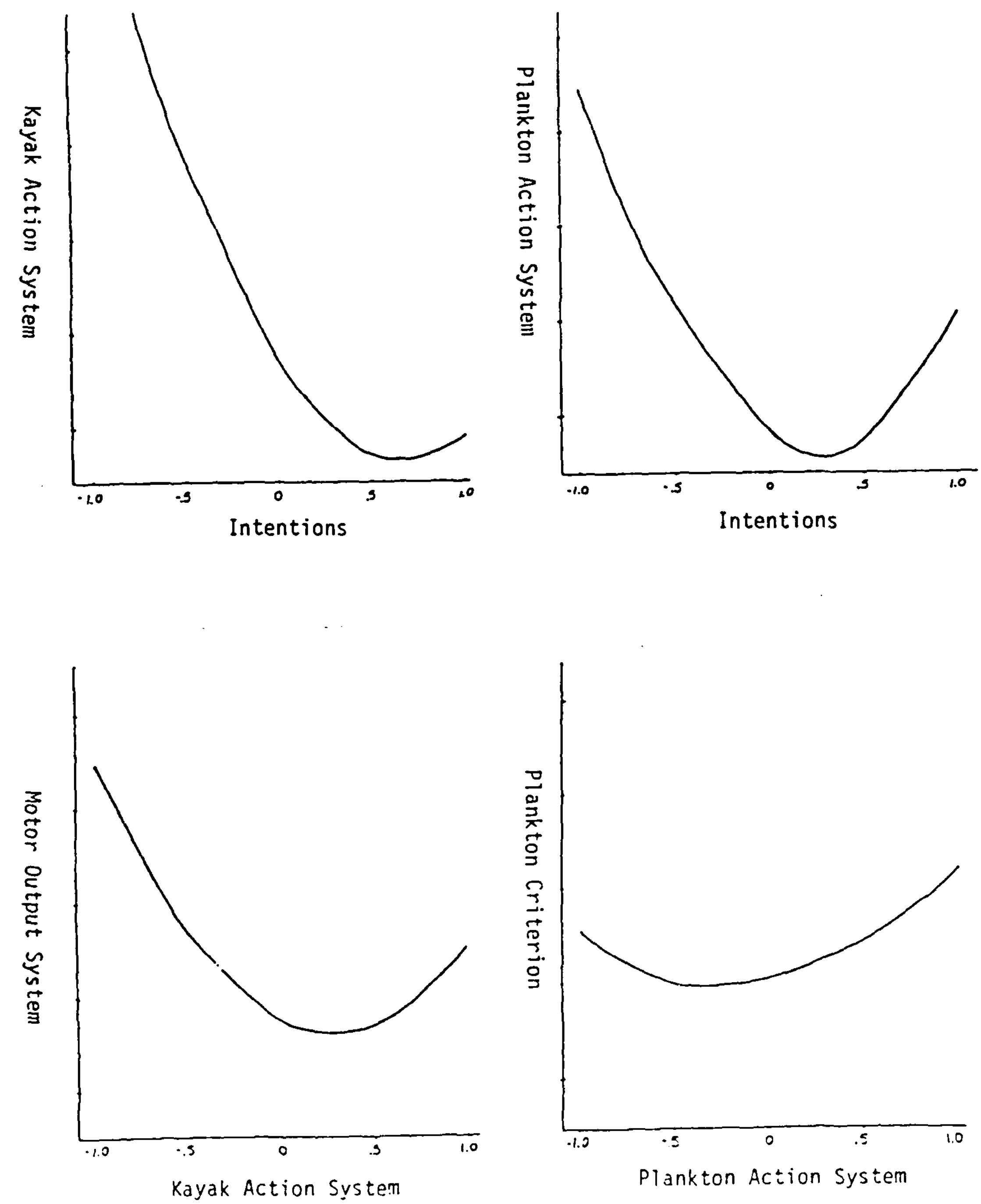


Figure 4-2

SD), performance worsened. However, the positive linear relation between intention and action provides a more plausible interpretation. The depicted influence between intention and criterion achievement is positive and linear. Thus, in regions below (to the left of) the nadir of the curve showing the relation between the action system and criterion achievement, the two influences counter each other. As the value of the action system increases above the lowest point along the curve (i.e., about -.5 SD or .242), the effects of intention and action become additive.

Thus at low levels, changes in either intention or efficiency are of little consequence. However, as intention increases, marked improvements in performance begin to occur. Additionally, differences in efficiency (i.e., action system activity) are of increasing importance relative to intention in explaining high levels of performance. Together with the small positive input from the motor system, these influences combine to explain 83 percent of the variance in subjects' performance of the plankton task

All depicted paths leading to performance of the kayak task are linear and of nearly equal influence. Intending to wreck kayaks (i.e., not staying near the plankton), following the appropriate rules, and changing direction frequently (and responsively) accounted for 50 percent of the variance in this task. No interactions or non-predicted paths met inclusion criteria.

The model requires several adjustments to fit the data. However, as most of these are minor, the basic structural aspects remains intact. All linear relationships are in appropriate directions and all met established magnitude criteria. Two

curvilinear relationships involving the estimated value of the kayak action system were revealed but could be artifacts of estimation. Curvilinear functions also relate the plankton action system to motor output and plankton criterion. An examination of these yields useful insights. In sum, the model provides a meaningful, consistent and interpretable context for describing the game's underlying structure.

4:3b BETWEEN-SUBJECTS VARIANCE

Figure 4-3 reflects the descriptive statistics, correlations and standardized regression equations for data reflecting between-subject variance. Reaction time is presented in milliseconds and reflects the average performance during trials 50 through 75 of a 100-trial, four-choice reaction task. The incidental learning measure is the number of correct responses to 20 post-task, computer-generated questions. (Five questions were not scored because they concerned opinions or were deemed to be misleading.)

The next four columns reflect hierarchic performance measures from the preceding analysis. The measure of intention and the plankton action system were taken from plankton priority trials and the measure of the kayak action system was taken from kayak priority trials. The number of moves was computed across all priorities. (Because conditions varied within priorities across single and dual task presentations, single task trials were omitted from the computation of average scores). The last three columns contain the criteria for each of the three types of priority conditions (i.e., kayaks destroyed during kayak priority trials, tonnes of plankton eaten during plankton priority trials and points

BETWEEN-SUBJECTS ANALYSES: DESCRIPTIVE STATISTICS,
ZERO-ORDER CORRELATIONS AND STANDARDIZED REGRESSION EQUATIONS
EXPERIMENT ONE
(n=20)

Variables	Individual Differences		Hierarchic Measures				Criteria		
			I	Ak	Ap	M	K	2K+P	P
	RT	IL	LT3P	CLQK	PACTP	MVST	KDK	PTSB	PEP
Mean	463	12.1	133.6	5.56	.347	64.4	10.6	28.3	14.5
SD	79	2.9	22.0	1.42	.056	11.6	3.0	8.0	8.1
Correlations:									
RT		-.38	-.18	-.60	-.47	-.58	-.78	-.57	-.35
IL			.61	.51	.64	.64	.51	.62	.57

Standardized Regression Equations

I= .06 RT + .63 IL
t(17) .27 3.03**
R^2=.37 F(2,17)= 5.05*

Ak=-.47 RT + .33 IL
t(17) -2.43* 1.73
R^2=.45 F(2,17)= 7.04**

Ap=-.26 RT + .54 IL
t(17) -1.38 2.86*
R^2=.47 F(2,17)= 7.65**

M=-.40 RT + .49 IL
t(17) -2.25* 2.79*
R^2=.55 F(2,17)=10.28**

K=-.68 RT + .25 IL
t(17) -4.43** 1.68
R^2=.66 F(2,17)= 16.39**

P=-.16 RT + .51 IL
t(17) -.76 2.41*
R^2=.35 F(2,17)=4.53*

PTS=-.39 RT + .47 IL
t(17) -2.16* 2.61*
R^2=.52 F(2,17)=9.20**

* p<.05 ** p<.01

Variables: RT= Four-choice reaction time; IL= Incidental learning; I= Intentions (less than three spaces); Ak= Kayak Action System (centre, not lined-up, one quadrant); Ap= Plankton Action System (one space percentage); M= Motor Output System (number of changes of direction); P= Plankton eaten; K= Kayaks destroyed.

Figure 4-3

scored during equal priority trials).

The next section of Figure 4-3 shows each of the linear correlations between the individual difference measures and the hierarchic and criteria measures. Because quickness is shown by lower reaction times, its correlations with other variables are negative. The measure of incidental learning shows similarly consistent positive correlations with other variables. In this respect, the task appears similar to many everyday skills; people who are quicker and "know" more, perform better.

The lower portion of Figure 4-3 shows standardized regression equations for each of the four hierarchic and three criterion measures. The equations are spatially arranged in accordance with their position in the model of task structure. For each variable, the standardized regression equation is presented with the beta weights associated with each of the individual difference measures. Because the beta weight is influenced by both the relative magnitude of the causal relationship and the variance of the predictor, it provides summary information concerning effects. This allows a direct comparison of individual difference influences on the respective measures (each was treated as a separate dependent variable).

The line below each equation contains the t statistic which shows the unique contribution each predictor variable made to the explanation of the total variance in the endogenous variable. The significance of t is the certainty appropriate in rejecting the null hypothesis (viz., the relationship shown by the subjects is not present in the general population). The bottom line shows the R^2 for the whole equation (the portion of the variance explained by

all the exogenous variables together) and the corresponding F ratio. The significance of F reflects the degree of certainty appropriate in rejecting the null hypothesis (viz., the sample of subjects were drawn from a population in which the multiple $R=0$).

The direct effects of the two individual differences explain significant portions of the variance in each of the performance measures ($p<.05$). Explanations for the measures associated with the kayak task are all significant at the .01 level. The two individual difference measures affect the two tasks differently. Somewhat surprisingly, the kayak task (originally developed to tap "higher order" decisional skills) was most closely related to simple reaction times and the plankton task (assumed to reflect the psycho-motor abilities) was more closely related to the ability to answer post-task questions. It is possible that the "awkward" control system dissociated performance from reactional abilities. The combined measures, total number of directional changes and points scored during equal priority trials, showed nearly equal contributions from both individual difference measures.

4:3c <u>WITHIN-SUBJECTS VARIANCE</u>

The previous analysis focussed on the influence of individual differences. In contrast, the analysis of within-subjects variance is concerned with the similarity of effects of different conditions on all subjects. The analysis is directed toward identifying the effects of conditions on the performance of the two tasks at different hierarchic levels. A common metric is a prerequisite for meaningful comparison.

The activities represented by the two tasks (viz., having a meal or being harpooned) are fundamentally incomparable. However,

if one is willing to forego ruminating about the symbolic implications of these activities, the development of a common metric is possible. The basis for this comparison lies in the repeated measures design. Since each subject performed the 17 trials of the game under the same variety of conditions, each subject's performance across all trials and conditions provides a common standard for describing performance.

Conversion to within-subjects standardized scores as described in the last chapter instantiates this approach. Often standardized scores are represented by "z-scores" which have a mean of 0.0 and a stand deviation of 1.0. A simple arithmetic transformation (multiplying the z-score by 10.0, then adding 50.0) produces an equivalent but more amenable distribution in that it avoids confusions involved with mixing negative and positive values. All performance measures were standardized to means of 50.0 and standard deviations of 10.0. A score of 50.0 implies "average" performance for subjects; scores of 60.0 or 40.0 represent performances one standard deviation above or below the mean respectively.

Standardization allows scores from different tasks to be plotted and compared. Figure 4-4 is a graphic representation of performance on the two criteria across the three priority conditions and four levels of practice. Standardized performance scores reflecting the number of kayaks crashed and tonnes of plankton eaten are represented along the ordinate axes. Levels of practice are shown along the abscissae. Single task trials (the first three and last two) were omitted because they contained several substantive differences from the dual task trials. Three

EFFECTS OF PRIORITY AND PRACTICE
ON STANDARDIZED MEASURES OF
KAYAK CRASHING AND PLANKTON EATING

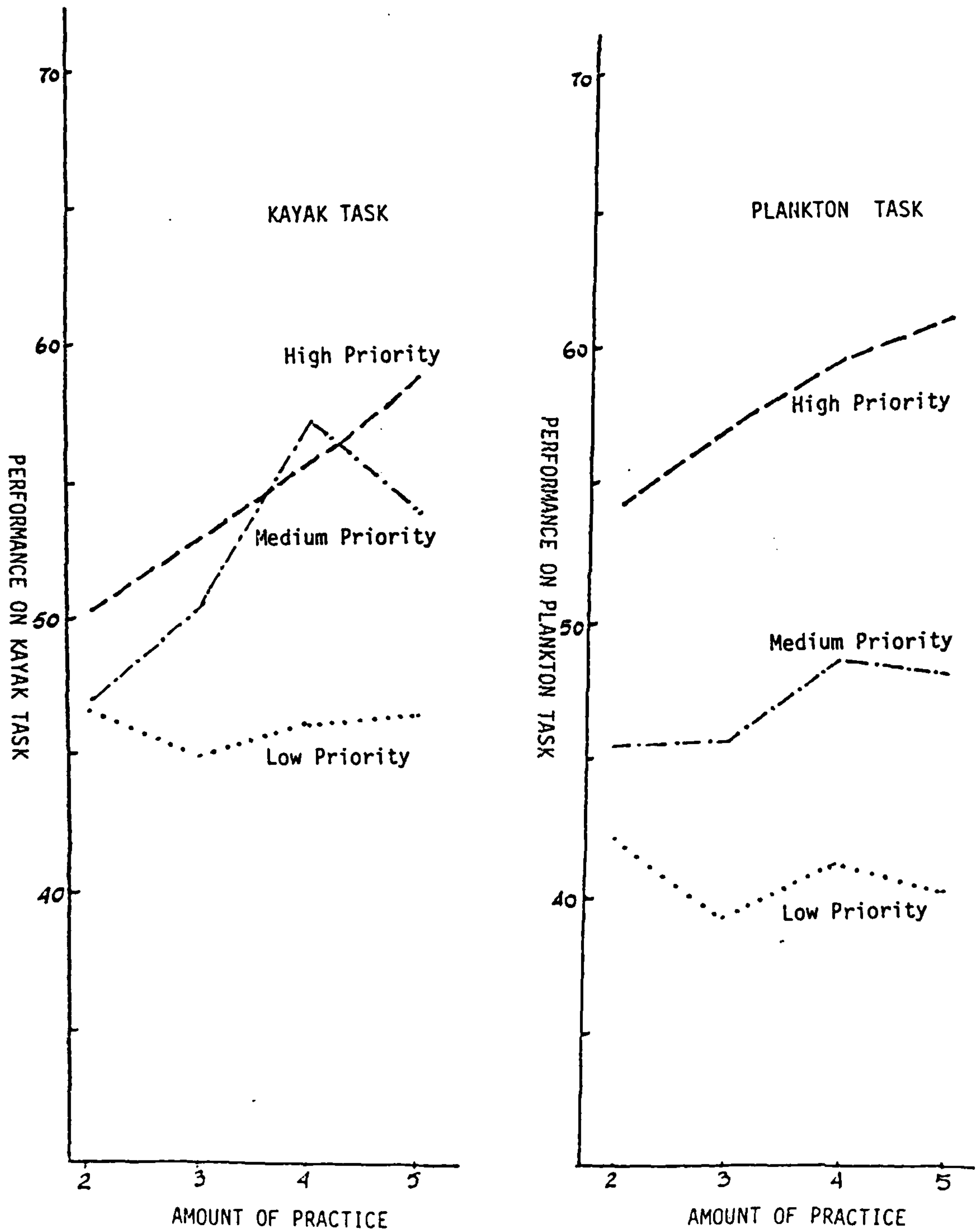


Figure 4-4

sequential trials comprised each "run" and this unit of measure was employed to reflect practice. Because the order of presentation was counterbalanced, the average amount of practice for each of the three priorities within each run was the same.

The three priorities are represented by different lines. Dashes represent performance when the task was to be given high priority. The dotted lines show performance during trials when the task was to be given low priority and the line with alternating dots and dashes reflects performance during equal-priority trials. Thus, performance on trials when kayaks were to be given priority is represented as a dashed line on the kayak graph and as a dotted line on the plankton graph. The four data points on each of the priority curves represent the average of 20 subjects' scores.

Several comparisons between the two tasks are immediately apparent. Although priority instructions appear to affect both tasks, the plankton task seems to show the greater effect (wider vertical spread of the three priority curves). Both tasks reflect the positive effects of practice, particularly during those trials when the respective tasks were given high priority.

There is also an indication that shifts from low to medium and medium to high priority have differential effects on the two tasks. For the kayak task, the greatest change in performance occurs when priority changes from low to medium (in fact, during the fourth run, performance was better during equal priority trials than during kayak priority trials). For the plankton task, the opposite appears to be true; shifts from medium to high priority are more effective than shifts from low to medium priority.

Although many aspects of the performance are apparent from

inspecting the graphs, it would be useful to be able to evaluate the significance of these characteristics objectively. Establishing statistical significance (i.e., the degree of certainty appropriate in rejecting the null hypothesis that the observed characteristic occurred by chance) is the appropriate general procedure. There are several alternative techniques for doing this. By default many researchers opt for pre-packaged analyses of variance for repeated measures. However, to the extent independent variables reflect quantitative rather than purely qualitative (i.e., nominal) differences, multiple regression offers considerable advantages in power and efficiency. Grouping continuous data results in the loss of information contained within the resultant groups.

Cohen and Cohen (Chapter 11, 1983) present an extensive "outline" of multiple-regression analysis of repeated measures designs. Standard multiple regression programs provide some valid information (i.e., the proportion of the total variance explained (R^2) and the unstandardized regression coefficients (B_i) for each independent variable). However, because these programs "assume" each observation is independent (thus relying on inappropriate degrees of freedom and, subsequently, standard errors), the statistical significance is over-estimated. By making appropriate adjustments to the degrees of freedom, appropriate values for the significance tests (i.e., the F ratio for the overall equation and the t statistic for each predictor) can be computed.

Several underlying statistical issues are not fully resolved. The focus of this thesis, however, is psychological rather than statistical. By relying on replication, convergent evidence and

cogent argument rather than merely derived statistical values, the dangers of being misled by inadvertently violating certain assumptions are ameliorated. The alternatives of employing only conventional analytic approaches or presenting a rigorous mathematical justification of the application of multiple regression are equally unattractive.

Figure 4-5 contains the regression equations for several performance measures. Each of these is composed of three lines. The bottom line shows the portion of the total within-subject variance explained (R^2) by the depicted equation. The F ratio is depicted on the same line. As Cohen and Cohen (Chapter 11, 1983) suggest, the appropriate degrees of freedom are: the product of the number of independent variables in the equation and the number of times the measure was repeated (viz., 12) and the product of the number of subjects, less the number of independent variables less one, and the number of times the measure was repeated (12). Thus each additional independent variable increases the degrees of freedom for the numerator by 12 and decreases the degrees of freedom for the denominator by 12.

The top line shows the unstandardized regression equation for each of the performance variables. Since all measures were transformed to means of 50.0 and standard deviations of 10.0, the regression coefficients are directly comparable even when employing the unstandardized coefficients. In fact, predicted values for each combination of the two independent variables (priority and practice) can be computed by simply entering the desired values into the equation. The middle line contains the t statistic for each of the independent variables in the regression equation.

REGRESSION EQUATIONS SHOWING WITHIN-SUBJECTS INFLUENCES
ON SELECTED PERFORMANCE MEASURES
FOR EXPERIMENT ONE

Intention	= 1.58 PRI	+ 1.86 P^2	+ .47 RUN		+ 36.45
t(192) =	.54	2.58**	1.56		
R^2 = .72	F (36,192) = 13.71**				
Pkt Act Sm	= 7.98 PRI		+ .85 RUN		+ 31.33
t(204) =	11.91**		1.73		
R^2 = .42	F (24,204) = 6.16**				
Qdrnt Str	= −5.16 PRI		−.07 RUN		+ 59.34
t(204) =	−8.38**		.14		
R^2 = .26	F (24,204) = 2.99**				
Drct Chngs	= 5.14 PRI		+ 2.26 RUN		+ 34.10
t(204) =	10.12**		6.05**		
R^2 = .40	F (24,204) = 5.67**				
Pkt Eaten	= −5.64 PRI	+ 2.46 P^2	− 1.55 RUN	+ 1.28 RXP	+ 44.94
t(180) =	−1.52	2.94**	1.66	2.95**	
R^2 = .66	F (48,180) = 7.28**				
Kyk Crshs	= −4.20 PRI		+ 1.86 RUN		+ 51.89
t(204) =	−5.83**		3.51**		
R^2 = .18	F (24,204) = 1.87*				

* $p < .05$ ** $p < .01$

Independent Variables:
- PRI - Priority Instructions (1- Kayaks; 2- Equal; 3- Plankton)
- P^2 - Curvilinear aspect of priority instructions (PRI * PRI)
- RUN - Amount of Practice (in 3-trial groupings) (2 through 5)
- RXP - Interaction between priority and practice (PRI * RUN)

Figure 4-5

Curvilinear and interactional influences are each represented by discrete variables (i.e., P^2 and RXP). Regressions for each of the variables discussed earlier were attempted. However, the proportions of variance for the kayak action system, staying in the central region, and lining up kayaks were insufficient to reject the general null hypothesis. In accordance with the "protected t" strategy (Cohen and Cohen, 1983), further analysis of these variables was not attempted.

The regression equations for plankton eaten and kayaks crashed can be compared with their graphical representations (Figure 4-4). There is a difference in the amount of variance explained in the two criteria. The equation for kayak crashing is only significant at the .05 level and thus instantiates the minimal sensitivity of this approach. However, the positive effect of priority (the negative coefficient reflects the coding) and practice are both highly significant. The equation implies each step in priority instructions (i.e., from low to medium and from medium to high) results in an increase of .420 standard deviations in kayak crashing. Independently, each 3-trial increment of practice resulted in an average improvement of .186 standard deviations. Unfortunately, the relatively small proportion of variance explained does not support further elaboration (i.e., the inclusion of variables reflecting curvilinearity or the apparent interaction).

Much more of the variance in the plankton task is explained by its regression equation ($R^2 = .66$). Even though this equation includes four independent variables, it is highly significant ($F(48,180) = 7.28$, $p<.01$). Both aspects of the data noted during

the visual inspection are significant. Both curvilinear (P^2) and interactional (RXP) terms assume the prior inclusion of terms reflecting main linear effects. Prior to the inclusion of curvilinear and interactional terms, the regression coefficients reflecting these main effects (7.13 PRI and 1.50 RUN) were both highly significant. (Although practice has nearly equivalent proportional influences on the kayak and plankton tasks, the effects of priority instructions were nearly twice as great on the plankton task.) The significant interaction between practice and priority ($t(180)=2.95$) implies the improvement in performance occurred in high priority conditions but not with low priority. In fact, the equation predicts that during kayak priority trials (PRI = 1), performance will decline slightly between runs 2 and 5.

The curvilinear aspect of the effects of priority (P^2) in the equation is not represented as a "curve" in Figure 4-4, but as the displacement of the central (equal priority) curve downward toward the low priority curve. The incremental increase in performance in going from low to medium priority was significantly less than the increment in performance which accompanied the shift from medium to high priority conditions. This might reflect the differential marginal utility of intention; however, it is also possible the curvilinearity reflects an intentional bias toward the kayak task during equal priority instructions. The regression equation for the intention measure (being within three spaces of the plankton) suggests subjects were biased toward the kayak task during equal priority trials (i.e., shows the same curvilinear relation). This was corroborated by inspecting raw data: there was a .15 SD shift toward the kayak task on equal priority trials. This does not

necessarily disprove the alternative differential marginal utility explanation, rather just renders it unnecessary.

For variables reflecting intention, the plankton action system and the stay in one quadrant rule, the influence of priority is significant but the effect of practice is not. Although practice appears to have equal and nearly significant effects on intention and the plankton action system, it is slightly negatively related to the staying in one quadrant strategy. Apparently this rule was not learnt with practice. In contrast, the number of directional changes, the motor output system indicant, reflects a strongly positive influence of practice. The regression coefficient suggests the the average number of directional changes increased .226 standard deviations with each successive run. The significant positive coefficient for priority implies subjects increased the number of directional changes by one half standard deviation for each increase in plankton priority.

4:4 DISCUSSION

Experiment One was an attempt to appraise the potential of adapting an arcade-type video game for use as an empirical tool. An attempt was made to develop a game which was sufficiently interesting and challenging to tap those aspects of behavioural integrality not elicited by traditional laboratory tasks. An attempt was also made to surreptitiously constrain and extensively measure subjects' performance to enable meaningful subsequent analysis. Simultaneously, efforts to develop appropriate analytic procedures for evaluating the data were undertaken. (The analyses just presented were developed during the course of the first three experiments.)

As an elaborate pilot study, Experiment One was very useful. Several strengths as well as weaknesses were revealed. Most subjects reacted very favourably to the game and appeared to put forth considerable effort to "save their whale". The fatigue one might expect to be associated with a two-hour experiment was not observed. Neither ceiling nor floor effects were encountered. Performance of the two sub-tasks appeared amenable to objective decomposition by regression techniques and supported the subsequent development of a feasible model of the task structure.

The between-subjects analysis suggested quicker and more knowledgeable subjects performed both tasks better. The within-subjects analysis of performance of the plankton task showed encouragingly strong effects of priority and practice (explaining 66 percent of the variance). In contrast, these two variables explained only 18 percent of the within-subjects variance in the performance of the kayak task. If the effects of these influences were not sufficiently clear, there seemed little reason to expect the presumably lesser effects of various verbal side tasks would show significant effects. Both subjects' wide variance in computer game experience and internal aspects of the game were suspected of introducing unwanted variance. Attempts to remedy the kayak problem are discussed in the next chapter.

The pattern reflected by the regression equations for within-subjects variance also deserves notice. Priority instructions had the greatest main effect on intention (Bp = 7.13) and the plankton action system (Bp = 7.98), while practice showed its greatest main effect on the motor output system indicant (Br = 2.26). The plankton-eaten criterion was the only measure to show a

significant interaction between practice and priority. Although data relating to the kayak criterion are too noisy to support similar statistical inferences, the graphical representation suggests the presence of a similar interaction. This provides useful convergent support both for the original hierarchic argument and the efficacy of the analyses employed.

Simply stated, these data suggest that intentions (and one action system) are most directly influenced by verbal priority instructions, that the motor output system shows the greatest influence of practice, and that criterion achievement involves an interaction between the two. However, these data were drawn from only 20 subjects; general replication is appropriate before further explanation.

A FUNCTIONAL EXAMINATION OF INTERMEDIATE COGNITIVE PROCESSES

CHAPTER FIVE

EXPERIMENT TWO - REFINEMENTS AND ADJUSTMENTS

5:1 INTRODUCTION

The results of Experiment One were encouraging, but also showed the need for changes. Experiment Two embodies many improvements. Most of the modifications introduced in this experiment were incorporated in later studies. Although many changes were made, caution was taken to preserve those aspects of the game which had shown promise. In a sense, Experiment Two was more a "redecoration" than a "reconstruction" of Experiment One.

5:2 METHODS

Again 20 subjects were randomly selected from the Oxford Subject Panel, but with an important difference: all were female. There were several reasons for this stipulation. Women represented a more homogeneous group in terms of video game experience. Selecting subjects with similarly sparse experience, seemed one way to minimize the apparently obscuring effects of individual differences. Subject Panel women are more "normally-distributed" than their male counterparts. The general distribution of subject panel males is rather bimodal (i.e., students and the long-term unemployed).

The apparatus was upgraded in several ways. Most noticeably, the portable black and white television was replaced by a 16 inch colour video monitor. The quality of the display was enhanced considerably and the colours themselves (the border was dark blue; the ocean, cyan; the whale, dark blue; the plankton, flashing yellowish-green; the icebergs, white; and the kayaks bright red)

gave the game a more polished appearance. Additionally, the 48K Spectrum was fitted with twin ZX Microdrives which reduced program loading time from several minutes to about 10 seconds and improved reliability to near perfect. Subjects sat 36 inches from the screen and video brightness and contrast were again adjusted for individual comfort. The main differences between the two experiments were contained in the game itself. These differences will be presented in a bottom-up sequence, starting with control characteristics and ending with general procedures and presentation schedules.

The game involved a slower average cycle time (i.e., 796 msec) due to the inclusion of several additional intra-cycle keyboard measures. Actually, the increase of 30 msec per cycle was imperceptibly small. What was noticeable, however, was the "improved" control system. By rewriting the program to minimize computer processing between subjects' inputs and the computer's responses (i.e., minimum lag time), the control characteristics changed greatly. The minimum lag was reduced from 360 msec to 200 msec and additional fixed processing was increased from 310 to 520 msec. This meant subjects had 67 percent more time to decide on directional changes. The temporal increment per kayak was also slightly reduced (from 80 to 70 msec). The control characteristics were thus slightly slower in rate, more responsive (less "lagged") and less variable. All these changes should enhance "system controllability" (Roscoe, 1980).

The number of cycles in each trial was shortened from 251 to 217, which reduced the time per trial to 2 minutes 52 seconds. "Single task" trials were omitted. The same constellation of 18

icebergs was presented on each trial (depicted in Figure 2-1). An iceberg arrangement was selected which did not involve icebergs being placed on any of the spaces along diagonal lines emanating from the kayak generation locations. Icebergs in these spaces often caused kayak crashes quite independently of subjects' efforts. Also subjects whose whales inadvertently "ate" these "critical" icebergs, subsequently lost an exorbitant number of points. Eliminating such icebergs helped reduce noise and strengthened the relationship between the quality of subjects' play and their scores.

Although the equations used to generate the plankton's random walk were unchanged, the plankton began each trial at four slightly different locations. By starting at different points the plankton's path passed under the iceberg clusters and rebounded off the upper and lower borders at slightly different locations. However, because the sequence of movements along the path was the same, subjects' performance was directly comparable (i.e., there was no difference in "difficulty") between conditions. This is an example of creating and enhancing an "illusion of randomness," an important factor in developing video games that are both interesting to subjects and useful to researchers.

Several important changes involved the kayak task. Previously when a kayak failed to crash into an iceberg and then reached the whale, it simply disappeared. In Experiment Two, when a kayak reached the whale, it also disappeared but this was marked by a series of beeps and an immediate decrement in subjects' score. The kayaks were no longer merely an opportunity to gain points; they now constituted a threat. For each priority, the points to be

gained for crashing a kayak were the same as those to be lost for getting harpooned (i.e., 10, 50 or 100). Subjects could (and sometimes did) end trials with negative scores. The total number of kayaks launched was reduced from 25 to 20 (roughly commensurate with the reduction in the number of cycles). Also the hint concerning icebergs was replaced by more accurate instructions:

> "The kayaks always move towards the whale, so the way to make them crash is to ensure the whale is on the opposite side of the nearest cluster of icebergs."

Additional kayak measures were taken. Each movement of each kayak was categorized as being diagonal (or not) and tabulated. The sum of non-diagonal moves provided a direct measure of "line-up time."

General procedures also changed. The single 100-cycle, four-choice reaction task was replaced by two 75-cycle tasks. This allowed the researcher to instruct subjects on the desirability of increasing their speed to a point where they were making a few errors (Rabbitt, 1981). Subjects were then familiarized with temporal control characteristics through adaptive "whale training." Subjects were given as many trials as necessary to reach the criterion of circumnavigating an iceberg 10 times in under 75 seconds (no other characters were present). Since subjects could not make the whale "go faster", meeting the criterion depended entirely on accurate and timely directional inputs.

Subjects then completed 15 game trials with the order of priority counterbalanced across subjects. After the last trial, subjects completed a 20-question incidental learning measure and then took the Embedded Figures Test (Witkin, et al., 1971). Total time for the experiment was again approximately two hours.

5:3a GLOBAL ANALYSES

The raw data analyses are shown in Figure 5-1. Means, standard deviations, correlations and the resultant task structure will be discussed in turn. In reviewing these data, several changes from the previous experiment are particularly relevant. The number of cycles was reduced from 251 to 217 cycles and because all subjects were women, prior video game experience was assumed to be reduced. Also the control system was improved, the iceberg hint deleted, points lost for the whale being harpooned and the same iceberg constellation presented on each trial.

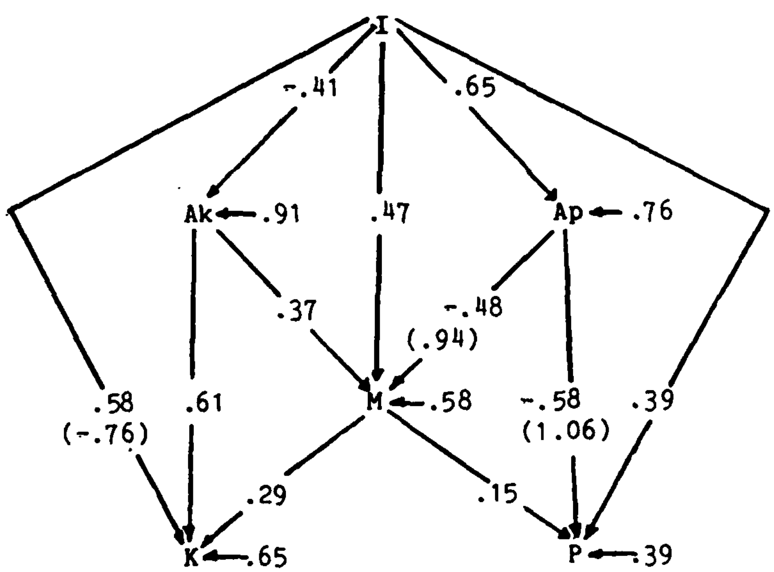
In relative terms, the measure of intention is nearly identical to Experiment One. Subjects' whales were within three spaces of the plankton 30 percent of the time (or 35 percent if the cycles on which they "scored" are added). The range of this measure was again constrained between -1.50 and +3.50 standard deviations of the mean giving the distribution a positive skew.

The measure of the kayak action system is a unit-weighted combination of the three rules reflected in Figure 5-1. Although the commitment to a single quadrant (QST) is proportionately the same as Experiment One, the proportion of cycles spent in the central area dropped from 42 to 35 percent. This is primarily due to the fact that shortening the game reduced the portion of the time the plankton spent in the central region. The improved control system is reflected by a slight increase in the plankton action system measure (from .294 to .313) and greater motor activity. The average of 61.0 changes of direction per trial implies subjects made one change every 3.56 cycles (or 2.8 seconds).

DESCRIPTIVE STATISTICS, ZERO-ORDER CORRELATIONS
AND TASK STRUCTURE FOR EXPERIMENT TWO*

Variables**	I	Ak	Ap	M	P	K	IBE	CEN	LUT	QST
Mean	64.7	5.03	.313	61.0	11.5	7.9	3.36	75.9	78.9	.94
SD	40.5	1.90	.142	18.4	13.4	3.4	2.47	30.0	15.5	1.30
I		-.41	.65	.53	.69	-.26	-.20	-.30	-.09	-.58
Ak			-.20	.15	-.23	.71	.06	.68	-.64	.55
Ap				.63	.76	.02	-.29	-.23	-.18	-.32
M					.75	.28	-.19	.09	-.36	-.18
P						-.10	-.24	-.22	-.15	-.37
K							-.16	.47	-.54	.31
IBE								.23	.10	-.01
Cen									-.21	-.07
LUT										.02

TASK STRUCTURE



* N= 300 (20 subjects X 15 trials)

**Variables: I= Intentions (less than three spaces); Ak= Kayak Action System (centre, not lined-up, one quadrant); Ap= Plankton Action System (one space percentage); M= Motor Output System (changes of direction); P= Plankton eaten; K= Kayaks destrcyed; IBE= Icebergs eaten; LUT= Line-up time; QST= Commitment to one quadrant strategy.

Figure 5-1

Changes in the performance of the two criterion tasks is also interesting. The average score of 11.5 tonnes of plankton represents an increase from 8 to 13 percent of the maximum. In contrast, the average of 7.9 kayak crashes represents approximately the same success ratio as in the previous trial (viz., 40 percent). Another aspect of these data is interesting. The number of icebergs eaten increased from 1.87 to 3.36 with the deletion of the "iceberg avoidance" hint. This suggests subjects were closely attending to instructions.

Despite all the changes, the correlation matrix is remarkably similar to the matrix for Experiment One. Intention (I), the plankton action system (Ap), number of directional changes (M) and tonnes of plankton eaten (P) are closely related ($.53<r<.76$). The correlations between performance on the kayak task and each of the three component rules (staying in the centre, not lining up kayaks and staying in one quadrant) all increased and the correlation with the unit-weighted action system measure (Ak) is quite strong ($r=.71$). The increase in the average number of icebergs eaten is accompanied by the emergence of generally negative correlations with most other variables. These are still, however, relatively small.

The task structure was derived by the procedure described earlier. All predicted paths were entered; then curvilinear exponentials, interactions and non-predicted paths were examined for inclusion. Variables with a "computed t" greater than 5.00 and a tolerance greater than .05 were entered sequentially. After all extra variables which met criteria were entered, the predicted paths were re-examined with respect to the "computed t" criterion.

Those failing to meet this criterion were shown as broken lines.

The depiction conventions are also the same as those employed in Experiment One. Numbers to the right of each endogenous variable reflect the error term. Path coefficients are standardized semi-partial regression coefficients (betas) and thus provide summary information reflecting the relative influence of each path. Where applicable, curvilinear aspects are indicated in parentheses below linear path components. Curvilinear components also involve "suppression" which makes the beta weights less directly interpretable.

The path structure is very similar to Experiment One but slightly more powerful. The proportion of variance explained for the kayak task increased from 50 to 58 percent and for the number of directional changes, increased from 48 to 66 percent. This is encouraging since the two primary purposes underlying many of the changes were to improve the predictability of the kayak task and to enhance the control system. The "effectiveness" of other paths is generally unchanged. Path coefficients are very similar to those reported previously. Similar curvilinear relationships between the plankton action system and the motor output system and plankton criterion are reflected by the respective beta weights and shown in Figures 5-2b and 5-2c.

The two curvilinear relations directly involving the kayak action system were not replicated, however, a new curvilinear relationship between intention and kayak crashes met inclusion criteria. This curve is shown in Figure 5-2a and warrants explanation. It is important to remember the measure of intent is structurally bounded between -1.5 and +3.5 standard deviations of

DEPICTION OF CURVES INDICATED
IN EXPERIMENT TWO TASK STRUCTURE

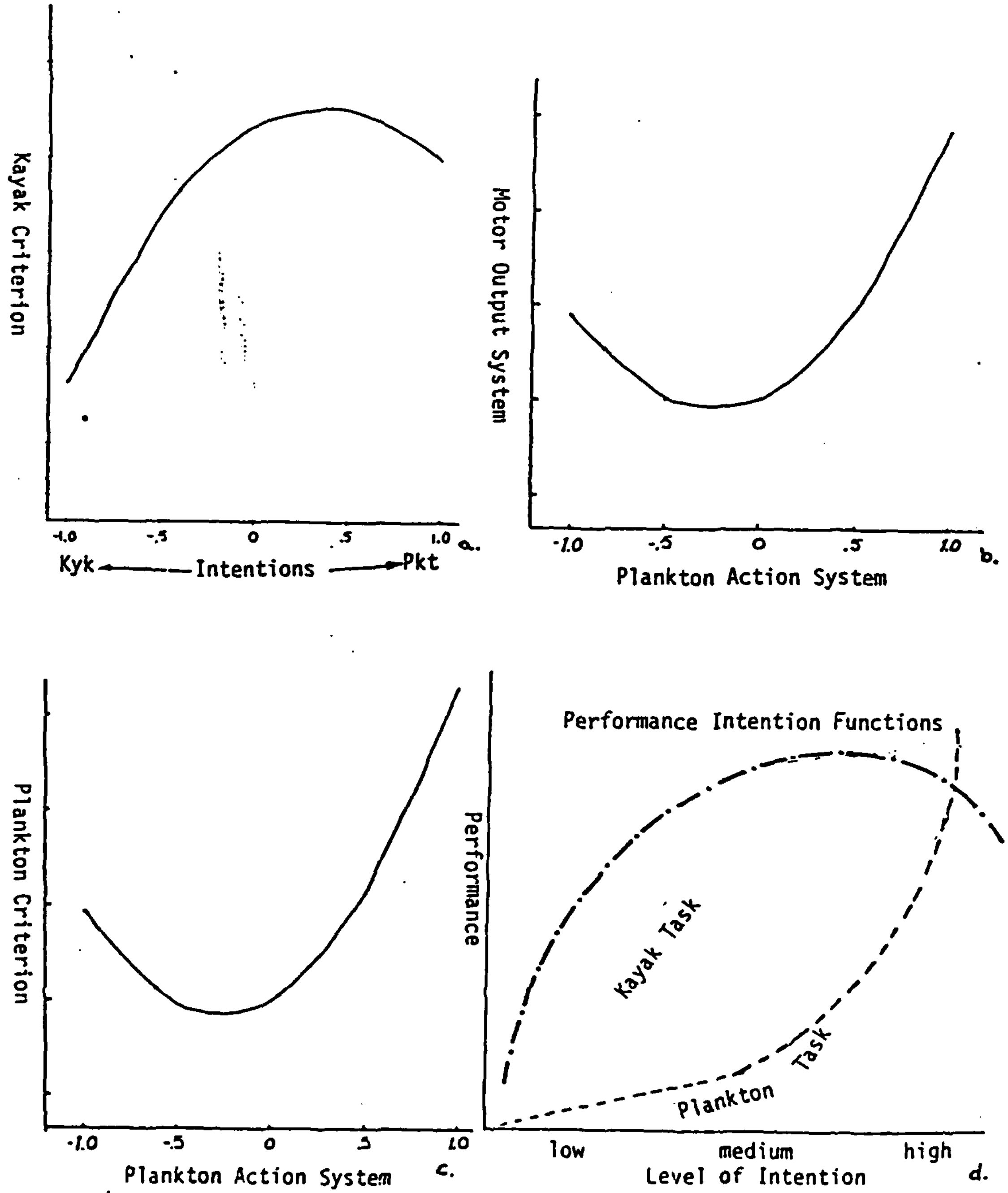


Figure 5-2

the mean. In this respect the negative linear correlation ($r=-.26$) reflects the influence of the skewed portion of the curve. Always staying near the plankton was incompatible with doing well on the kayak task. What is not so apparent is the explanation for the positive relation shown in the left arm of the curve.

If the positive linear influence of the kayak action system and its negative relationship with intention (to eat plankton) ($r=-.41$) is considered, a plausible interpretation emerges. Basically, in the region to the left of the mean of the intention measure (kayak orientation), the two influences counteract each other, but in the region to the right (plankton orientation) the two influences act in concert to account for reductions in kayak performance with reduced kayak intention. In other words, shifts from low to moderate levels of intention (to wreck kayaks) produce positive effects on kayak performance: shifts from moderate to high levels of intention are much less efficacious and can actually be counter-productive if not accompanied by action system increases.

This contrasts sharply with the conceptual relations between components in the plankton task (replicated from Experiment One). Shifts of intention (to eat plankton) from low to moderate levels are relatively ineffective. The influence of the action system becomes increasingly important as intention rises beyond one standard deviation above the mean. Intention and the commitment of "resources" would thus be reflected by substantively different functions for the two tasks. The differences suggested by the foregoing analyses can be represented by alternative performance resource functions. Two such curves are depicted in Figure 5-2d.

Again the model of the task's relation-structure receives

general support. All linear relationships are in the predicted directions. The two curvilinear relations involving the plankton action system were replicated. The two curvilinear relations involving the kayak action system have been replaced with appropriate and relatively strong linear relationships. The curious curvilinear relationship between intention and performance of the kayak task provides an interesting contrast to the plankton task. One depicted path (motor output's influence on plankton performance) fell below the t criterion. This might reflect the close correlation between the plankton action and motor output system measures. However, the lack of interactions or non-predicted paths meeting inclusion criteria again supports the general efficacy of the model.

5:3b BETWEEN-SUBJECTS VARIANCE

Descriptive statistics, correlations and standardized regression equations are presented in Figure 5-3. Reaction time is again presented in milliseconds, but is based on the average reaction time for correct responses on all 75 cycles of the second four-choice reaction task. The next measure reflects the score on the Embedded Figures Test administered at the end of the experiment. Although several questions were deleted and others modified, the incidental learning instrument is very similar to that employed in Experiment One.

The hierarchic measures and criteria are comparable to the previous experiment as well. Although it initially appears the intentional commitment has decreased slightly (from 53 to 48 percent of the cycles during plankton priority trials), when the scoring cycles are considered the degree of commitment is nearly

BETWEEN-SUBJECTS ANALYSES: DESCRIPTIVE STATISTICS,
ZERO-ORDER CORRELATIONS AND STANDARDIZED REGRESSION EQUATIONS
EXPERIMENT TWO
(n=20)

Vari-	Individual Differences			Hierarchic Measures				Criteria		
				I	Ak	Ap	M	K	2K+P	P
ables	RT	EF	IL	LT3P	CLQK	PACTP	MVST	KDK	PTSB	PEP
Mean	455	8.0	11.7	104.5	6.19	.391	61.0	9.3	27.4	21.2
SD	78	5.3	2.3	19.7	1.56	.101	15.0	2.8	10.7	14.0
Correlations:										
RT		-.61	-.57	-.58	-.60	-.75	-.78	-.67	-.75	-.76
EF			.62	.65	.50	.54	.40	.51	.47	.54
IL				.33	.39	.59	.50	.65	.58	.59

Standardized Regression Equations

I=-.35RT + .58EF - .23IL
t(16)-1.51 2.34* -.96
R^2=.50 F(3,16)= 5.37**

Ak=-.47RT + .21EF - .01IL
t(16)-1.81 .79 -.03
R^2=.38 F(3,16)= 3.31*

Ap=-.60RT + .02EF + .24IL
t(16)-2.89* .09 1.12
R^2=.60 F(3,16)= 8.09**

M=-.80RT - .19EF + .16IL
t(16)-3.94** -.89 .79
R^2=.62 F(3,16)= 8.88**

K=-.46RT - .02EF + .40IL
t(16)-2.05 -.10 1.79
R^2=.55 F(3,16)= 6.56**

P=.82RT - .04EF +1.93IL -1.51RXL
t(16)1.22 -.20 2.44* -2.22*
R^2=.71 F(4,15)=9.03**

PTS=-.65RT - .10EF + .28IL
t(16)-3.12** -.44 1.31
R^2=.60 F(3,16)=8.05**

* p<.05 ** p<.01

Variables: RT= Four-choice reaction time; EF= Embedded Figures score; IL= Incidental learning; RXL= Interaction between RT and IL; I= Intentions (less than three spaces); Ak= Kayak Action System (centre, not lined-up, one quadrant); Ap= Plankton Action System (one space percentage); M= Motor Output System (changes of direction); P= Plankton eaten; K= Kayaks destroyed.

Figure 5-3

the same as before (i.e., 58 percent). Higher average scores for the plankton action system and the slight proportional increase in the number of directional changes are attributable to the improved control system.

Although proportional averages for the criteria of both tasks improved, plankton showed the larger increment. Despite these increases, average performance was still well below optimal (i.e., 47 percent for the kayak task and 24 percent for the plankton task). In fact, optimal performance on the kayak task would be represented by a z-score of +3.8 and for the plankton task +4.9. The proportional improvement in the combined criteria was slightly less than the improvements in the single priority tasks.

Although the length of the game was reduced by 14 percent in that there were 34 fewer cycles, standard deviations on five of the seven performance measures increased from Experiment One. The attempt to minimize the effects of individual differences by selecting only female subjects was apparently unsuccessful.

Zero-order linear correlations between the individual difference and performance and criteria measures are also shown in Figure 5-3. The relatively strong intercorrelations between the separate individual difference measures do not bode well for using multiple regression to "unpack" the separate influences of these exogenous variables. However, the correlations between reaction time and the game variables are all stronger than those previously recorded. Embedded Figures Test scores and the incidental learning measure showed similarly consistent, and expectedly positive relations with performance variables. Not too surprisingly, subjects who were quick, field independent and provided correct

answers to post-task questions, performed better.

The standardized regression equations contain several interesting features. Apparently the improved control system tightened the relation between performance on the plankton task and the measures of individual differences. However, what was gained for the plankton task appears to have been lost for the kayak tasks (i.e., more predictors explain a smaller portion of the performance variance). As a result of the much stronger relationship between predictors, the number of significant individual t values dropped considerably (from 9 of 14 in Experiment One to 6 of 22). Reaction time appeared to be the singly most important predictor, making significant unique contributions to the plankton action system, number of directional changes and the number of points scored during equal priority trials.

One particularly noteworthy aspect of these equations is shown by the significant interaction between reaction time and incidental learning in predicting performance of the plankton task. After each of the main variables was entered, potential interactions were inspected, as were potential curvilinear relations. Those found to be significant were included. The interaction reflected in the regression equation for plankton eaten is depicted in Figure 5-4. It shows that subjects who were quicker showed greater increases in performance with increased knowledge (as reflected by incidental learning scores). Several similar interactions had just missed inclusion in Experiment One.

To summarize the standardized regression equations, three individual difference measures explain significant portions of the variance at the .01 level for six of the seven performance measures

EXPERIMENT TWO INTERACTION BETWEEN
REACTION TIME AND INCIDENTAL LEARNING
PREDICTING PERFORMANCE ON PLANKTON TASK

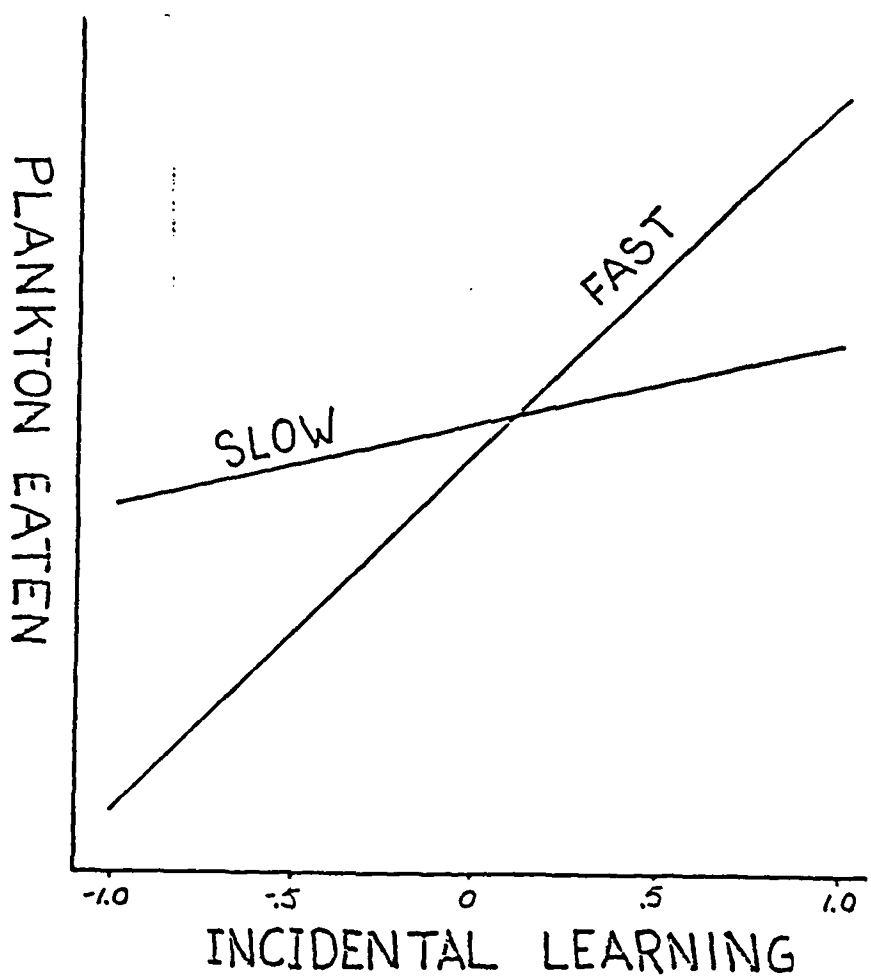


Figure 5-4

and at the .05 level for the seventh (the kayak action system). However, because of the relatively close inter-relations between the exogenous variables, individually identified influences on particular performance measures were less clear. The improvement in the control system, exclusive employment of female subjects, and numerous other minor changes had the net effect of improving the predictability of the between-subject variance on the plankton task. However, these changes decreased the proportion of between-subject kayak task performance variance explained by the same individual difference measures.

5:3c WITHIN-SUBJECTS VARIANCE

Figure 5-5 shows the effects of priority and practice on the two tasks. Scores were again standardized to means of 50.0 and standard deviations of 10.0. All 15 trials used in computing the standard scores are represented on the two graphs (one of each priority for each run). Each data point represents the average relative performance of all 20 women.

The strong effect of priority (shown by the vertical spread of the horizontal curves representing each priority condition) is apparent. Improvement with practice is shown by the positive slopes of the curves, particularly in the high and medium priority conditions for both tasks. The upward displacement of the medium priority curve for kayak crashing suggests a non-linear effect of priority. The opposite effect (i.e., a downward shift in the medium priority curve) is no longer apparent in the plankton task.

Again regression analyses were employed to identify the relative effects of priority and practice (and potentially their interactional and curvilinear influences). The resulting equations

EFFECTS OF PRIORITY AND PRACTICE
ON STANDARDIZED MEASURES OF
KAYAK CRASHING AND PLANKTON EATING

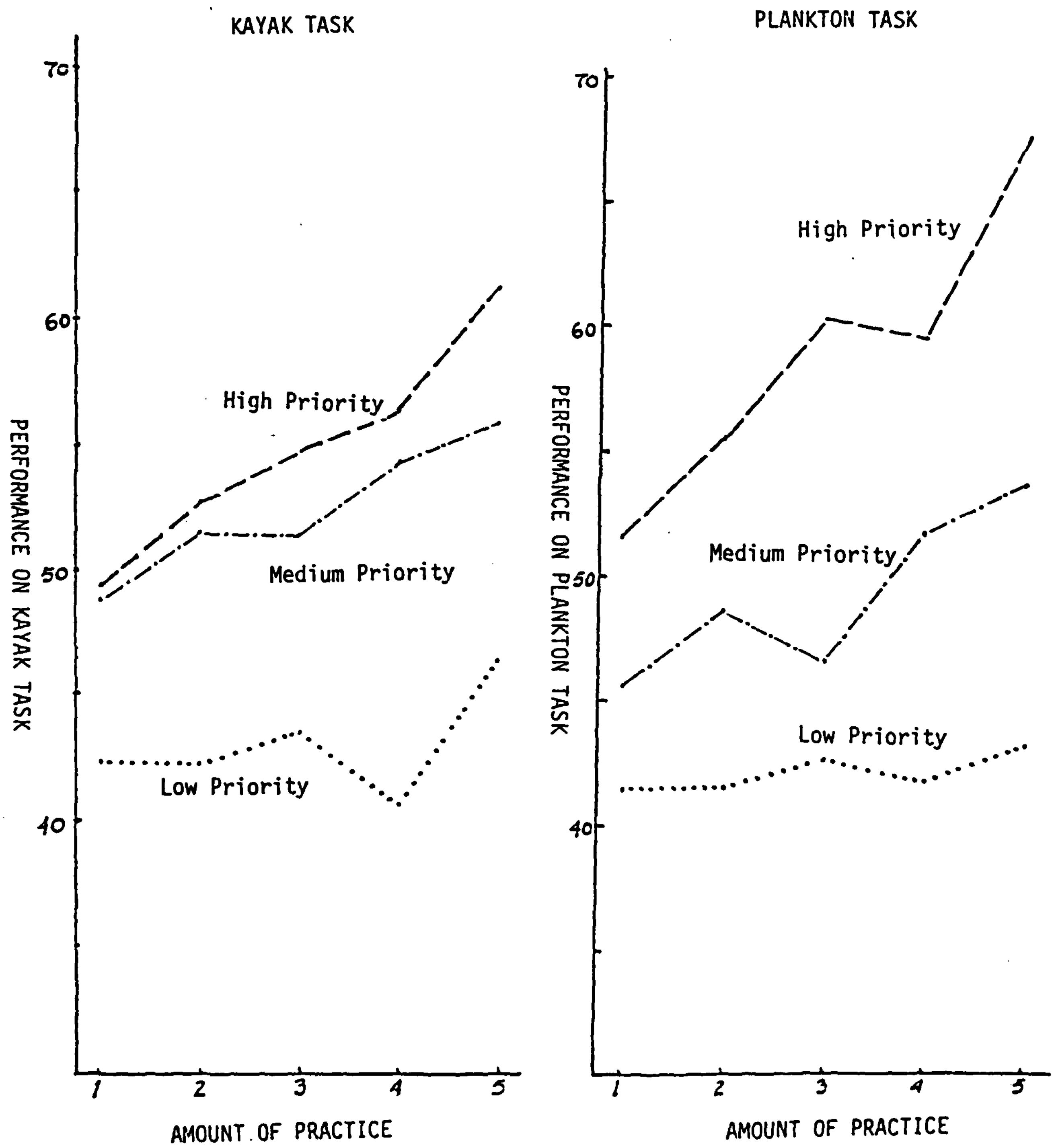


Figure 5-5

are shown in Figure 5-6. The comments concerning performance graphs are largely supported by the statistical analyses. Although the total amount of variance explained for the plankton task decreased slightly to 63 percent, the proportion of the within-subjects variance explained for the kayak task nearly doubled to 35 percent. This is still less than for the plankton task but is sufficient to support a more detailed descriptive analysis.

Both the interaction of practice and priority (RXP) and the curvilinear component of the priority effect (P^2) are significant ($t(225) = 2.32$ and $t(225) = 3.15$ respectively) for the kayak task. In the previous experiment, a complementary (i.e., opposite) curvilinear effect in the plankton task was attributed to a bias toward kayaks during equal priority trials. It is possible the same explanation might apply here. However, inspection of the intention variable shows no sign of bias (as would be reflected by a significant curvilinear component). Inspecting the raw data revealed a .02 SD bias toward plankton during equal priority trials. An intentional bias toward kayaks during equal priority trials was not the explanation. The alternative explanation based on the differential marginal utility of intention gains indirect support.

Performance of the plankton task reflects the positive influences of priority instructions and practice and their positive interaction (RXP). The disappearance of the curvilinearity noticed in the previous experiment deserves a brief explanation. It was shown that this curvilinearity reflected a bias toward the kayak task during equal priority trials. There was no evidence of a

REGRESSION EQUATIONS SHOWING WITHIN-SUBJECTS INFLUENCES ON SELECTED PERFORMANCE MEASURES FOR EXPERIMENT TWO

Intention = 9.97 PRI + .48 RUN + 28.62
t(255) = 24.95** 2.12*
R^2 = .71 F (30,255) = 20.81**

Pkt Act Sm = 15.37 PRI + 2.19 P^2 + 1.52 RUN + 24.93
t(240) = 3.61** 2.08* 4.28**
R^2 = .37 F (45,240) = 3.13**

Kyk Act Sm = -6.79 PRI + 1.63 RUN + 58.67
t(255) = -11.64** 1.63
R^2 = .39 F (30,255) = 5.43**

Centre Reg = -4.64 PRI + 1.06 RUN + 56.11
t(255) = 6.93** 2.73**
R^2 = .18 F (30,255) = 1.87**

Qdrnt Str = -6.37 PRI + .69 RUN + 60.69
t(255) = -10.35** 1.94
R^2 = .30 F (30,255) = 3.64**

Drct Chngs = 6.38 PRI + 2.96 RUN + 28.35
t(255) = 11.81** 9.58**
R^2 = .48 F (30,255) = 7.84**

Pkt Eaten = 3.57 PRI - 1.30 RUN + 1.63 RXP + 37.02
t(180) = 3.28** -1.83 4.90**
R^2 = .63 F (45,240) = 9.08**

Kyk Crshs = 11.07 PRI - 3.48 P^2 + 3.73 RUN - 1.04 RXP + 39.16
t(225) = 2.37* 3.15** 3.82** 2.32*
R^2 = .35 F (60,225) = 2.02**

* $p < .05$ ** $p < .01$

Independent Variables:

PRI - Priority instructions (1- kayaks; 2- equal; 3- plankton)
P^2 - Curvilinear aspect of priority instructions (PRI^2)
RUN - Amount of practice in 3-trial groups (1 through 5)
RXP - Interaction between priority and practice (PRI * RUN)

Figure 5-6

similar bias during this experiment. Increasing the amount of time subjects had to respond to the plankton by printing it earlier in each cycle, made this task relatively "easier" (i.e., increased the payoffs for a given output). This change had a less direct effect on the kayak task. In their efforts to gain the maximum points, subjects shifted their relative attention toward performance of the relatively easier task (viz., plankton). However, even with nearly equal attention to the two tasks, the curvilinearity which appears in the plankton action system suggests the increasing marginal utility of intention.

The measures reflecting two of the three rules which comprise the kayak action system supported significant regression equations. Both priority and practice had a positive influence on subjects staying in the central region suggesting this was an acquired strategy. The effect of practice was less strong (and not statistically significant) on subjects staying in one quadrant but the effect of priority was very strong. The "quadrant" rule was apparent or "salient" to many subjects from the beginning of the game and not derived through playing experience. Once again practice and priority did not yield sufficient explanations of within-subjects variance in the line-up time and icebergs eaten variables.

The number of directional changes, the indicant of the motor output system, showed independent positive effects of practice and priority for plankton. The main effect of practice was reflected most strongly in this variable (the RUN coefficient for kayak crashing is artificially elevated by the interaction).

The within-subjects analysis of these data are encouraging.

The effects of priority instructions and practice both appear clearly (and significantly) in most measures. Although the analysis identifies the generally positive effects of both intention and practice on both tasks, subtle differences in the nature of these influences on the two tasks are suggested. Intention appears to have a stronger direct effect on the plankton task than on the kayak task. The effect of intention on the plankton action system suggests that the effectiveness of intention increases as the level of intention increases. In contrast, analysis of kayak task performance suggests the opposite relation; that the effectiveness of intention decreases as the level of intention increases. These effects are not due to a bias during the equal priority trials but rather suggest a differential marginal utility of intention (and presumably the allocation of additional cognitive "resources"). This functional distinction will be pursued in further studies.

5:4 DISCUSSION

These results generally support those reported in the previous chapter. The raw data suggest subjects were performing at levels relatively free of either ceiling or floor effects (i.e., in a region where performance should be most sensitive to competing demands for intermediate cognitive processes). The improved keyboard control system and better measure of kayak line-up time helped to strengthen the relations comprising the model of the underlying task structure. This general hierarchic framework was again indirectly supported.

Between-subjects analysis indicated that the "homogeneously minimal experience" strategy was not very successful. Although

individual differences explained a greater proportion of performance on the plankton task, they explained less between-subjects variance for the kayak task. Because the individual difference measures were more closely interrelated ($.57<r<.62$), regression analysis was less able to differentiate their effects on different aspects of game performance.

In contrast to the lack of general analytic improvement on the between-subjects results, analyses of the within-subjects variance was very promising. The effects of both priority instructions and practice were apparent in most performance measures. Despite the many changes from Experiment One, certain patterns reappear in the regression equations of within-subjects data. The most significant influence of priority instructions is to be found in the measures of intention. The strongest main effect of practice again occurs in the indicant of the motor output system. With the reduced noise in the measurements of performance on the kayak task, both tasks show significant interactions between priority and practice. The consistency of these results with both the original arguments for the hierarchic measurements and the findings from Experiment One reflect favourably on the task, its measurement and the analyses employed.

The results also indicate interesting functional differences in the two tasks. The kayak task appears to benefit much more from initial increases in intention than does the plankton task. If the allocation of more processing resources is assumed to be a concomitant of increased intention, these differences suggest differing marginal utilities of resources within each task. These differences also suggest that over the range of intention elicited

by the different priority instructions the performance resource functions differ significantly between the two tasks.

For the kayak task this function appears to be convex and for the plankton task concave (see Figure 5-2). This distinction is consistent with the designed differences in structure of the two tasks (i.e., because of its inherent uncertainty, the plankton task should require active parameter specification by processing mechanisms and the kayak task, because of its greater complexity but lower uncertainty, should allow greater reliance on implicit knowledge). If one assumes even moderate levels of intention are sufficient to activate parameter specification by internal representations, the kayak curve appears to rely more heavily on this mode of parameter specification.

At this point these arguments are still very speculative. What is most important is that a tool, a method of employing it and techniques for analysing the data derived from its use have produced coherent results. This degree of sensitivity or "power" (which reflects the task, its measurement and the analysis of the measurements) was an absolute prerequisite for attempting to investigate the more important research questions concerning the functional characteristics of the human information processing system. This experiment meets that requirement.

A FUNCTIONAL EXAMINATION OF INTERMEDIATE COGNITIVE PROCESSES

CHAPTER SIX

EXPERIMENT THREE - INITIAL MODEL TESTING

6:1 INTRODUCTION

The purpose of the first two experiments was to develop a tool (and the necessary procedures, measurements and analyses) to garner information relevant to the model presented in Chapter One. The results discussed in the last two chapters support the employment of the Save the Whale game. The game proved to be very engaging; subjects often commented on their enjoyment or how quickly the time had passed. Performance of the two sub-tasks was free from ceiling and floor effects. Most subjects learned the game quickly, but few developed expert abilities. A set of measures corresponding with a logical hierarchy showed robust consistency and provided plausible explanations for the achievement of both criteria. While individual differences accounted for a large portion of the variance, the technique of using regression analysis with by-subject standardized scores yielded encouraging results by clearly showing the effects of priority and practice.

The information processing model presented in Chapter One had several distinctive features. Process and content were functionally segregated (i.e., attentional resources and knowledge). Knowledge was defined as information concerning relation structures in the outside world. In contrast, attentional resources were defined as agnostic, limited-capacity, temporally-constrained processing mechanisms. Within each entity, distinctions between verbal and nonverbal components were proposed. For knowledge, this distinction followed the demarcation suggested

by Reber (1976) or Berry and Broadbent (1984) between implicit and explicit knowledge. For processing mechanisms, Baddeley and Hitch's (1974) working memory framework was adopted with special emphasis on the distinction between the articulatory loop and the central executive.

Because the game was a visuo-manual activity, combination with auditory-verbal side tasks should involve only minimal "structural similarity" interference (Wickens, 1984). Brown (et al., 1969) employed a similar approach in their study of the effects of verbal side tasks on driving. In their experiment, drivers negotiated a track containing obstacles forming "gaps" while simultaneously answering questions. Half the gaps were slightly more narrow than the automobile; drivers were to detour around these "impossible" gaps. Drivers' performance in manoeuvering the car through possible gaps and their decisions not to attempt impossible ones provided separate measures of performance. The verbal side task interfered with decision-making but left motor activities unimpaired.

More recently, Hitch and Baddeley (1976) investigated the effects of combining a range of memory loads with several types of primary tasks. They found the number of items to be remembered affected the amount of interference encountered. If subjects only had to remember two or three items, there was minimal interference. However, as the memory load was increased to six items, performance of the primary task consistently declined. From these results, Hitch and Baddeley (1976) argue that tasks such as articulatory suppression or ones with minimal memory loads (viz., less than 1.5 seconds of verbal material) can be relegated to a subsidiary

mechanism specially suited for verbal processing (i.e., the articulatory loop) and not interfere with concurrent general processing. In contrast, if the verbal memory task involved six or more items, the capacity of the articulatory loop was exceeded and interference with other processing was almost certain. Hitch and Baddeley's (1976) method of systematically varying memory load levels seemed ideally-suited for combination with the video game.

This method was recommended by Maryanne Martin who had successfully employed it to demonstrate differential processing of dominant and non-dominant meanings of homographs (Martin, 1982, 1984). Her data show the 3 letter memory load interferes with processing of non-dominant meanings but shows facilitatory effects on the processing of the dominant meaning of the homographs.

6:2 METHOD

Ten male and ten female paid "volunteers" between the ages of 18 and 38 from the Oxford Subject Panel took part in this three-hour experiment. Participation was restricted to the "student or equivalent" portion of the panel. Although all subjects had sucessfully completed all scheduled activities for earlier experiments, several required more time and encouragement than others. Subjects who had never "touched" a computer before often displayed initial anxiety. Many of them had completed little formal education. The "student or equivalent" (roughly translated as "high school graduate") criterion was adopted out of convenience and as a precaution against subjects not being able to combine the game with a verbal side task.

The apparatus remained unchanged but the game was slightly modified. By deleting several unnecessary measurements and

processes and rewriting others, the minimum lag time was reduced by 20 percent (from 200 to 160 msec). Additional fixed processing time was decreased slightly (from 520 to 510 msec) but the increment per kayak remained the same (70 msec). Thus the whale controls were more "responsive", the average cycle time decreased from 796 to 747 msec and, because total cycles remained the same, the duration of each trial decreased to 2 minutes 42 seconds. The iceberg constellation, kayak launch schedule, plankton starting points and path structure all remained the same.

Subjects completed two 75-trial, four-choice reaction tasks and adaptive whale training before being introduced to the game. Subjects then accomplished 9 "practice" trials. After a short break, they were taught to perform the verbal side tasks and then completed two additional sets of 9 trials combining different game priorities and levels of the side task.

The side tasks involved subvocal rehearsal and report of either 1, 3 or 5 letters chosen from the set: F,H,J,L,M,Q,R,S,Z. The control condition employed a single letter and the two memory loads contained strings of either three or five letters chosen at random without replacement from the set. The experimenter first announced the string (at a rate of about one letter every three-quarters of a second), then 25 seconds later tapped a pen on the table top as a signal for the subject's response.

After the response, the experimenter replied "correct" (if appropriate), "close" (if a single letter was incorrect or pair of letters transposed) or "incorrect" (if there was more than a single error). Subjects were encouraged to maintain "correct" performance throughout. In the control condition, the experimenter repeated

the same letter six times then immediately signalled for a response which subjects also repeated six times. Memory items for the 3-letter load were repeated twice but only once for the 5-letter condition. This equalized the verbal material input and output across the three conditions while systematically increasing the information the material contained.

Each subject completed all nine possible combinations of priorities and verbal memory side tasks twice. The order of presentation was counterbalanced across four groups (each containing three members of one gender and two of the other). Two of the groups accomplished the first set of trials in a kayak-equal-plankton rotation and the other two in the reverse rotation. Groups from each rotation accomplished the side task levels in different orders (viz., 305053530 or 035350503). After the first 9 experimental trials, subjects took a short break. The presentation schedule for the second set of 9 experimental trials was a "mirror image" of the first set (i.e., the first trial of the second set was the same priority combined with the same side task as the last trial of the first set).

Thus, the average level of practice for the two trials of each priority - side task combination was the same. Also for every set of three trials, subjects completed one trial from each priority under one of each of the three side task conditions. This was more simple to perform than explain. Subjects' score sheets were annotated so each trial showed the appropriate priority and side task. Once a subject began a trial, the cues from the experimenter (i.e., saying one, three or five letters) were sufficient to define the side task. The only information subjects

needed to remember was the game priority and this was reflected by each score change.

At the end of the trial, subjects recorded their scores on both subtasks from the monitor display and were told their combined score on the side task by the experimenter (i.e, "1" for each correct string, "0" for each close string and "-1" for each incorrect string). After the final trial, subjects completed the Espoused Strategies Worksheet, the computer-generated incidental learning questions and the Embedded Figures Test.

6:3a GLOBAL ANALYSES

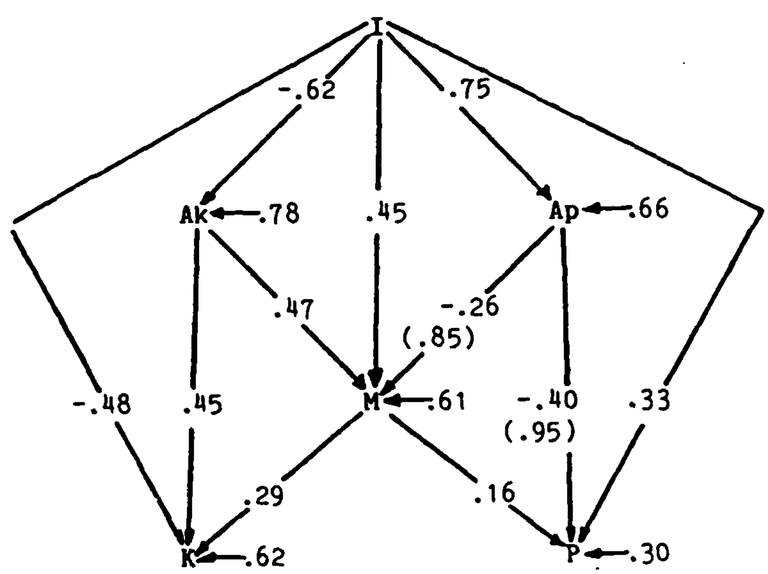
Overall descriptive statistics show marked differences from previous experiments. Subjects' whales stayed near the plankton approximately 42 percent of the time and improved their average plankton action system score (i.e., efficiency) by 20 percent. Improvement is also reflected by the number of times subjects changed the whale's direction of travel. The mean of 74.8 changes per trial implies effective inputs every 3 cycles (2.17 second). Performance on both tasks improved considerably. The average tonnes of plankton eaten nearly doubled from 11.5 to 19.4 and the average number of kayak crashes increased from 7.9 (40 percent) to 9.9 (50 percent). Subjects also stayed in the central region more (45 percent of the cycles) and reduced the average number of cycles they were "lined-up" with kayaks from 78.9 to 68.4 (a 13 percent decrease).

These improvements could be attributed to any of three changes: better subjects (i.e., using students and also reintroducing male subjects with greater video game experience),

DESCRIPTIVE STATISTICS, ZERO-ORDER CORRELATIONS
AND TASK STRUCTURE FOR EXPERIMENT THREE*

Variables**	I	Ak	Ap	M	P	K	IBE	CEN	LUT	QST
Mean	72.2	4.96	.376	74.8	19.4	9.9	3.16	97.4	68.4	.78
SD	43.7	2.07	.171	22.3	19.0	3.8	2.22	43.9	12.9	1.35
I		-.62	.75	.55	.78	-.60	.13	-.69	.08	-.50
Ak			-.48	-.07	-.51	.73	-.14	.76	-.63	.67
Ap				.67	.88	-.41	.12	-.52	.04	-.43
M					.75	-.01	.09	-.11	-.19	-.22
P						-.44	.05	-.54	.06	-.43
K							-.19	.74	-.43	.33
IBE								-.05	.12	-.11
Cen									-.26	.31
LUT										-.04

TASK STRUCTURE



* N= 540 (20 subjects X 27 trials)

**Variables: I= Intentions (less than three spaces); Ak= Kayak Action System (centre, not lined-up, one quadrant); Ap= Plankton Action System (one space percentage); M= Motor Output System (changes of direction); P= Plankton eaten; K= Kayaks destroyed; IBE= Icebergs eaten; LUT= Line-up time; QST= Commitment to one quadrant strategy.

Figure 6-1

more practice (subjects each completed 27 trials) or the further improvement of the control system. Any negative effects caused by the introduction of verbal side tasks are obscured by these positive influences at the general level of analysis.

Unfortunately these improvements had other implications. During equal priority trials, each success on the kayak task was worth twice as many points as each success on the plankton task. This scoring ratio resulted in nearly unbiased performance during equal priority trials in the previous experiment. However, the improvement in the average performance of the plankton task (7.9 successes) was nearly four times as great as the improvement in the kayak task (2.0 successes). Since subjects were instructed to earn as many points as possible, greater improvement in plankton performance induced a bias toward the plankton task during equal priority trials. The data show an 8-cycle (.18 SD) bias toward the plankton task during equal priority trials. Further evidence of this bias appears in subsequent analyses.

The correlation matrix shows familiar but enhanced relations between variables. Achievement of the plankton criteria is very closely associated to measured intention, plankton action system and motor output ($.67<r<.88$). The kayak task also shows much stronger relations to intention and kayak action system ($r=-.60$ and $+.73$ respectively). The correlations between the number of icebergs eaten and other variables remain low.

Similarly, the task structure reflects a strengthened pattern. The model components predict the performance of both criteria slightly better than previously; the depicted paths explain 91 percent of the variance in the performance of the

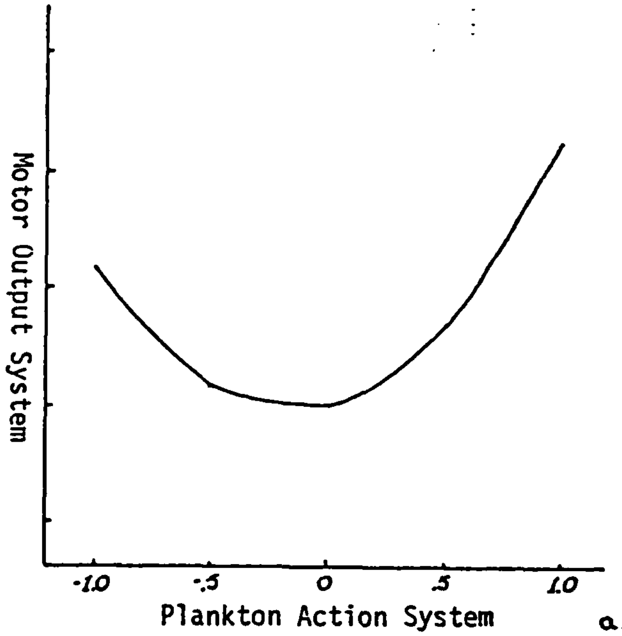
plankton task and 62 percent of the variance in the kayak task. Intention shows a stronger effect on the activity of both action systems (perhaps a manifestation of practice), alone explaining 66 percent of the variance in the plankton and 39 percent of the variance in the kayak action systems.

The non-linear relationship between the plankton action system and motor output system and the amount of plankton eaten shown in Figure 6-2 are nearly identical to those encountered earlier. The non-linear relationship concerning the influence of intention on kayak crashing was not replicated. Again no interactions, nor non-predicted paths met entry criteria (i.e., "computed t" greater than 5.00 and tolerance greater than .05)

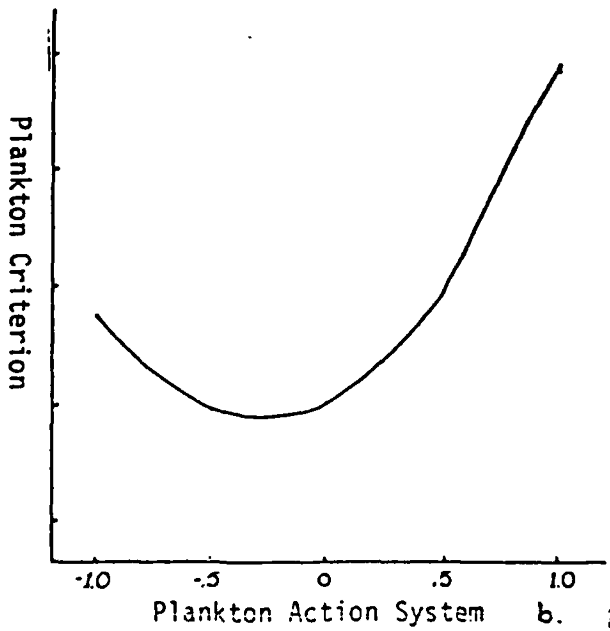
Performance of the memory side task was very good. Not too surprisingly, performance during the no load condition was perfect and nearly perfect under the three letter memory load. There were, however, decrements apparent in the five letter memory load (mean = 4.96, SD = 1.27). This average suggests subjects omitted a single letter or transposed a pair of letters during their recitation of one of the six strings of five letters presented each trial.

Before turning to an analysis of between-subjects variance, a discussion of the Espoused Strategies Worksheet is appropriate. One of the advantages of using computer games is the opportunity to take multiple measures and objectively analyse their relationships. The summary of the relation-structure discerned from all trials across all experiments provides a robust description of which activities were related to the achievement of each criterion. These provided an objective base-line for evaluating subjects' espoused strategies. Discrepancies between observed performance

DEPICTION OF CURVES INDICATED
IN EXPERIMENT THREE TASK STRUCTURE



a.



b.

Figure 6-2

and explicit selections thus reflect the extent to which subjects were able to identify the actual "rules" underlying their performance. Large and interesting differences between the two tasks emerged.

Table 6-1 contains these data for both the kayak and plankton tasks. For each task, four rules are listed in order of their relative objective importance. The overall correlation between the activities described by each rule and the achievement of the respective criteria is listed in the first column. The espoused rating is one half subjects' mean rating for the effectiveness of the rule on a five point scale ranging from +2.0 to -2.0. The derived ratings thus ranged from +1.0 to -1.0 with absolute values reflecting the relative strength of espoused relationships and the sign showing the direction of the relation. The differences between the values in the two columns show the correspondence between what subjects did and what they said. The absolute value of these differences is shown in the third column. The sum of these discrepancies indicates the disparity between the espoused rules and the actual structural relations inherent in the task. Correspondence (shown by the absence of differences) reflects the "salience" of the task's relation-structure.

The difference in the salience of the two tasks is apparent. The strategies subjects espoused for accomplishing the kayak task were incompatible with the regularities reflected by their performance. The rule subjects believed to be most important (viz., not eating icebergs) only accounted for 2 percent of the variance in criterion achievement. In contrast, rules which accounted for 20 percent of the variance (not turning away from or

COMPARISON BETWEEN ACTUAL AND ESPOUSED
RULES FOR ACCOMPLISHING TWO TASKS
(EXPERIMENT THREE)

KAYAK TASK				PLANKTON TASK			
	Utilities		Abslt		Utilities		Abslt
Rules	Obj.	Esp.	Diff.	Rules	Obj.	Esp.	Diff.
Stay in the central area.	.55	.10	.45	Always turn twd the pkt.	.78	.83	.05
Don't turn away from the kyks.	.45	-.37	.82	Stay near the plankton.	.76	.93	.17
Ignore the plankton.	.34	.13	.21	Ignore the kayaks.	.34	.03	.31
Don't eat icebergs.	.15	.75	.60	Don't eat icebergs.	.02	.10	.08
Total discrepancy			2.08	Total discrepancy			.61

Table 6-1

AVERAGE RELATIVE SUBJECTIVE
RATINGS OF PRIORITIES
(n = 20)

DIFFICULTY

P K E
Least 3-----------------------2-----------------------1 Most
2.85 1.65 1.50

COMPLEXITY

P K E
Least 3-----------------------2-----------------------1 Most
2.80 1.75 1.45

UNCERTAINTY

P K E
Least 3-----------------------2-----------------------1 Most
2.50 2.00 1.50

Priorities
P = Plankton E = Equal K = Kayak

Figure 6-3

lining-up with the kayaks) were rejected (i.e., received average ratings in the wrong direction). The best rule (i.e., staying in the central region) accounted for 30 percent of the variance in kayak wrecking but was rated as being nearly irrelavant (+.10). The close relationship (i.e., relatively slight differences) in the actual and espoused rules for the plankton task provides a sharp contrast. Subjects "knew" that staying close to the plankton and always turning toward it were the most important rules to follow.

Subjects' average rankings (responses to the bottom portion of the Espoused Strategies Worksheet) are shown in Figure 6-3. The letters above each scale reflect the priorities and the numbers below them, their average rank order from the 20 subjects. Most (but not all) subjects rated equal priority trials as being the most difficult, complex and uncertain. Similarly, the majority of subjects also rated the kayak task as being more difficult, complex and uncertain than the plankton task. The distinction between the two tasks proposed earlier (viz., that the kayak task was higher in complexity but lower in uncertainty than the plankton task) was not recognized by most subjects. However, as the results of the espoused strategies for wrecking kayaks suggest, popular concurrence and validity are not necessarily the same. The plankton task was (at least) rated as being more uncertain than complex and conversely that the kayak task was rated as being more complex than uncertain.

6:3b BETWEEN-SUBJECTS VARIANCE

One of the important changes in this experiment involved restricting subjects to the "student or equivalent" portion of the subject panel. The individual difference measures reflect effects

BETWEEN-SUBJECTS ANALYSES: DESCRIPTIVE STATISTICS,
ZERO-ORDER CORRELATIONS AND STANDARDIZED REGRESSION EQUATIONS
EXPERIMENT THREE (n=20)

Vari-ables	Individual Differences RT	EF	IL	ES	Hierarchic Measures I LT3P	Ak CLQK	Ap PACTP	M MVST	Criteria K KDK	2K+P PTSB	P PEP
Mean	423	11.6	14.3	4.3	116.5	6.65	.506	74.8	12.9	39.8	36.0
SD	43	3.9	2.2	1.8	5.1	1.49	.100	16.4	2.7	11.2	14.6
Correlations:											
RT		-.35	-.12	-.25	-.06	-.52	-.67	-.66	-.58	-.67	-.70
EF			.35	.25	.07	.54	.49	.60	.64	.57	.54
IL				-.10	.18	.52	.37	.54	.58	.48	.39
ES					-.07	.12	.31	.16	.19	.20	.24

Standardized Regression Equations

I=-.04RT + .01EF - .18IL
t(16) -.17 -.03 .69
R^2=.04 F(3,16)=.20 n.s.

Ak=-.06RT -2.73EF -1.21IL +4.00IXE
t(16) -.36 -2.72* -2.22* 3.03**
R^2=.72 F(3,16)= 9.68**

Ap=-.57RT + .21EF + .23IL
t(16)-3.21** 1.14 1.28
R^2=.56 F(3,16)= 6.86**

M=-.18RT -2.00EF(+2.43E^2)+ .43IL
t(16)-1.08 -2.35* (2.73*) 3.56**
R^2=.81 F(4,15)=16.34**

K=-.41RT - .36EF + .40IL
t(16)-2.78* 2.34* 2.75*
R^2=.70 F(3,16)=12.50**

P=-.58RT + .26EF + .23IL
t(16)-3.61** 1.50 1.44
R^2=.63 F(4,15)=9.27**

PTS=-.20RT -2.05EF(+2.47E^2)+ .37IL
t(15)-1.03 -2.12 2.43* 2.70*
R^2=.76 F(4,15)=11.84**

* p<.05 ** p<.01

Variables: RT= Four-choice reaction time; EF= Embedded Figures score; (E^2)= Non-linear aspects of EF; IL= Incidental learning; IXE= Interaction between IL and EF; I= Intentions (less than three spaces); Ak= Kayak Action System (centre, not lined-up, one quadrant); Ap= Plankton Action System (one space percentage); M= Motor Output System (changes of direction); P= Plankton eaten; K= Kayaks destroyed.

Figure 6-4

of the increased selectivity. The faster mean reaction time (423 msec) and reduced standard deviation (43 msec) suggest a more capable and homogeneous sample. The higher embedded figures score (11.6) and smaller standard deviation (3.9) corroborate the increased capability. Improvement in incidental learning could be attributed either to more capable subjects or increased practice.

The fourth individual difference measure reflects the validity of subjects' espoused strategies - the explicit rules subjects might employ in performing the tasks. Subjects' ratings of potential rules for each task were compared with the objective relationships between the activity and criterion achievement to derive a measure of correspondence. Scores from both tasks were added together to yield a combined measure.

Most performance measures reflect the combined influences of more capable subjects and more practice. Intention is an appropriate exception to the general increase. Logically, increases in ability and practice should show stronger effects on action and motor output systems. These results support the distinctions made between the hierarchic measures. Because the kayak action system is the average of conformity to three rules, the increase (above the 5.00 adjusted null) implies a larger portion of the variance in one or more of the components was related to changes in priority. The plankton action system indicant shows an even more positive shift.

Marked improvements were shown in all criteria. Using data from Experiment Two as a baseline, average scores increased by 39 percent for the kayak task, 45 percent for the equal priority task and 70 percent for the plankton task. However, if average scores

are first converted so they represent proportions of the objective optima (i.e., 20 kayaks crashed or 90 tonnes of plankton eaten) improvements in the two tasks appear to be about the same. Performance on the kayak task improved from an average of 47 percent to 65 percent of optimal and performance on the plankton task improves from 24 to 40 percent. Even with these improvements, "perfect" scores are still sufficiently remote (+2.63 SD for the kayak task and +3.70 SD for the plankton task) to prevent ceiling effects.

The correlation matrix shows weaker correlations among the four individual difference measures. This lack of multi-colinearity should improve the effectiveness of regression analyses in separating their influences. Reaction time correlates well with all performance measures except intention. The Embedded Figures Test and incidental learning scores also show strong positive correlations with performance measures other than intention. Espoused strategy scores appear to be much less sensitive predictors than the other measures. Apparently, knowing valid, specific rules was less important than having a general familiarity with the task. In keeping with Cohen and Cohen's (1983) axiom for regression analysis ("less is more") the espoused strategy measure was omitted from subsequent regressions.

The next portion of Figure 6-4 contains the standardized regression equations. Consistent with the low correlations, individual differences do not explain a significant portion of the variance in intention. Other regression equations, however, provide relatively strong explanations and reveal some interesting relationships. The significant interaction shown between

incidental learning and the embedded figures measure in predicting activity of the kayak action system is depicted in Figure 6-5c. Amongst relatively field-independent subjects, those with higher incidental learning scores followed the appropriate rules for kayak crashing more closely. However, amongst field-dependent subjects (i.e., those with low embedded figures scores), higher incidental learning was associated with less rule following activity. Although the same interaction was not statistically significant in predicting the actual performance of the kayak task, the significant negative loading of the Embedded Figures Test score suggests a counter intuitive advantage for field dependent subjects after the positive effects of greater quickness and knowledge are taken into account.

Two other performance measures reflect unusual relations between field dependence and performance. The curves showing the relation between Embedded Figures Test scores and the total number of direction changes and points scored during the equal priority trials are nearly identical. Both imply that some subjects who performed well during the game did badly on the embedded figures task. Also subjects who were near the mean on the embedded figures test performed very poorly at combining tasks and changed directions less frequently during the game trials. However, both effects must be considered in the context of significant positive influences of incidental learning on performance. Samples of 20 subjects are insufficient to clearly establish individual differences; replication is more appropriate than explanation.

The regression equations for both the plankton action system and criteria are refreshingly simple. Subjects who were quicker

DEPICTION OF BETWEEN-SUBJECTS
CURVILINEAR RELATIONS AND INTERACTION
FOR EXPERIMENT THREE

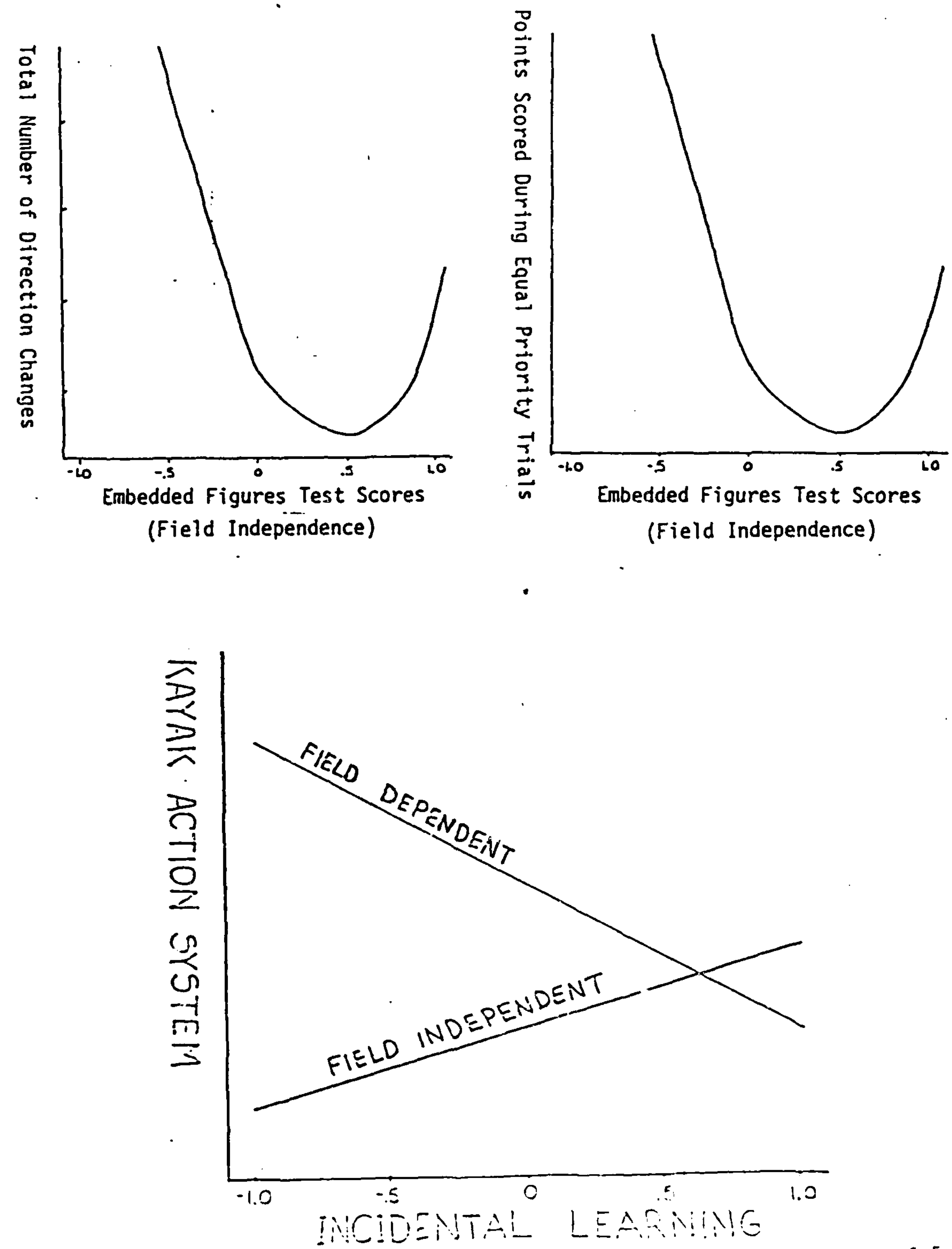
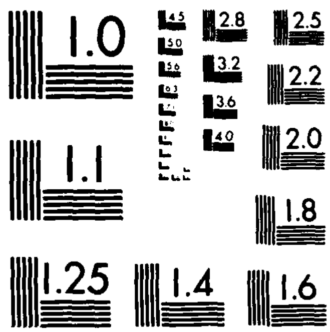


Figure 6-5

AD-A171 768 A FUNCTIONAL EXAMINATION OF INTERMEDIATE COGNITIVE PROCESSES(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH D B PORTER 1986 AFIT/CI/NR-86-155D 3/4

UNCLASSIFIED F/G 5/10 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

did better. Although being field-independent and showing greater incidental learning had expectedly positive effects, these influences were not statistically significant.

6:3c WITHIN-SUBJECTS VARIANCE

Data for each subject was again standardized to means of 50 and standard deviations of 10. Performance measures were treated as separate dependent variables. The influences of priority, practice and memory load were evaluated by multiple regression analyses for each dependent measure. Only data from the experimental trials (runs 4 through 9) were used for the regressions because the three initial practice runs (9 trials) did not involve side tasks and thus were not directly comparable with the other trials. The independent variables did not explain significant portions of the variance in the measures of kayak lined-up time, the one quadrant strategy nor the number of icebergs destroyed.

As in previous experiments, priority shows strong effects on all performance measures and are particularly marked for intention and measures relating to the plankton task. The appearance of the significant curvilinear effects of priority on intention and subsequently the two action systems can be attributed to the bias toward eating plankton during equal priority trials. As discussed earlier, this bias reflects subjects' attempts to maximize points by doing more of the "easier" task (i.e., plankton).

In comparison to the previous experiments, the effects of practice appear to be considerably diminished. In fact, the contribution of practice is only significant for the plankton criterion. One reason for this is an artifact of the research

REGRESSION EQUATIONS SHOWING WITHIN-SUBJECTS INFLUENCES
ON SELECTED PERFORMANCE MEASURES
FOR EXPERIMENT THREE

		PRI	P^2	RUN	MLD	Constant
Intention	=	25.43 PRI	- 3.13 P^2	- .10 RUN	- .27 MLD	+ 17.42
t(270)	=	4.47**	2.23*	.26	.84	
R^2	=	.49	F (72,270) = 3.60*			
Pkt Act Sm	=	22.60 PRI	- 3.10 P^2	+ .54 RUN	- .38 MLD	+ 18.09
t(270)	=	7.25**	4.02**	2.47*	2.20*	
R^2	=	.67	F (72,270) = 7.61**			
Kyk Act Sm	=	-25.03 PRI	+ 4.08 P^2	+ .46 RUN	+ .06 MLD	+ 74.58
t(270)	=	-4.11**	2.71**	1.11	.17	
R^2	=	.29	F (72,270) = 1.53*			
Centre Reg	=	-10.91 PRI		+ .32 RUN	- .25 MLD	+ 72.56
t(288)	=	11.70**		.72	-.68	
R^2	=	.33	F (54,288) = 2.63**			
Drct Chngs	=	8.69 PRI		+ .63 RUN	-.77 MLD	+ 34.36
t(288)	=	11.51**		1.73	-2.57**	
R^2	=	.33	F (54,288) = 2.63**			
Pkt Eaten	=	12.07 PRI		+ .57 RUN	- .54 MLD	+ 24.26
t(288)	=	23.64**		2.33*	-2.70**	
R^2	=	.67	F (54,288) = 10.83**			
Kyk Crshs	=	-8.60 PRI		+ .60 RUN	+ .13 MLD	+ 61.74
t(288)	=	11.23**		1.64	.42	
R^2	=	.31	F (54,288) = 2.40**			

* $p < .05$ ** $p < .01$

Independent Variables:

PRI - Priority instructions (1- kayaks; 2- equal; 3- plankton)
P^2 - Curvilinear effects of priority instructions (PRI^2)
RUN - Amount of Practice in 3-trial increments (4 through 9)
MLD - Memory load (0- no load; 3- letters; 5- letters)

Figure 6-6

strategy; in order to focus analysis on the effects of memory load, the 9 practice trials were excluded from the regressions. As with many skills, the greatest improvements occur during the earliest trials. Although this tendency was not sufficiently strong to support the inclusion of the curvilinear exponent of practice (i.e., RUN^2), the removal of the initial 9 trials diluted the effect of practice. In spite of this, performance on the plankton task still shows a significant main effect. The unstandardized regression equation (B_r = .57) suggests performance increased .06 SD with each successive run.

Although both the number of directional changes and performance on the kayak task showed similar improvements, neither was significant. This is due to the smaller proportion of variance explained in these two measures. The deletion of the early trials may also account for the disappearance of the interactions of practice and priority from the regression equations for the criteria.

The effect of memory load on each of the performance measures is shown by the MLD variable. As suggested earlier, performance on the memory load task was generally very good, but it is also important to ensure decrements were spread equally across conditions. Since performance in both the 0 and 3 letter memory load conditions was nearly perfect, only the 5 letter condition was analysed. Practice and priority together accounted for only 10.5 percent of the total variance. Subjects' performance during the second experimental set of 9 trials (particularly immediately after the break) was slightly inferior to their performance during the first set. In general, however, side task performance (ergo, the

processing resources involved therein) was equivalent across all conditions.

Memory load was coded as a continuous variable with three values corresponding to the three conditions (i.e., 0, 3 or 5). The use of a single variable is the most efficient coding for regression purposes (c.f., using two dummy variables). However, this presumes the effects of the two memory loads are linear and continuous. If the argument that the two levels of memory load involve different mechanisms (i.e., the articulatory loop for the 3 letter load and additionally the central executive for the 5 letter load), there is reason to suspect non-continuous effects. Significant deviations from linearity would be reflected by the memory load exponent (MLD^2). This variable was not significant for any of the performance measures. It can therefore be assumed the observed effects of memory load are adequately represented by the single variable.

Memory load caused significant decrements in both the number of directional changes and tonnes of plankton eaten. Although the significance of the effects is slightly greater for the criterion measure, the size of the effect on the motor output indicant is greater (B_m = -.77 for directional changes and -.54 for plankton eaten). On average, under the 5 letter memory load condition subjects' total directional changes decreased by .39 SD (about 8 changes) and their whales ate .27 SD (about 5 tonnes) less plankton. The initial detrimental effect of memory load, however, appears in the plankton action system measure (B_m = -.38, $t(270)$ = 2.20 $p<.05$). Although memory load also has a small negative influence on intention (B_m = -.27), this effect is not significant.

These equations suggest the verbal memory side task significantly impairs performance of the plankton task. If one assumes a hierarchic organization, these decrements appear to originate in the action system and subsequently depress both motor output and criterion achievement. During the initial set of experimental trials, relative to their respective control conditions, the number of directional changes were depressed by .2 SD for kayak priority trials, .4 SD for equal priority trials and .5 SD for plankton priority trials.

The effects of the memory load on the kayak task are quite different. Although none of the effects are significant both the kayak action system and the kayak criteria show positive rather than negative effects with increasing memory load. Both effects are small but the fact they are positive is sufficient to allay arguments that the lack of decrements merely reflects a lack of measurement sensitivity or analytic acuity.

By focussing on performance of the criteria when each was to be given priority, the differential effects can be represented graphically. Figure 6-7 shows these graphs. It should be noted the regression analyses are based on data from all experimental trials but the graphs represent only data from that third of the trials with the specified priorities.

Within the graphs, each data point reflects the average standardized performance of all 20 subjects. Performance during the first set of trials is shown by a dotted lines and performance during the second set by alternating dots and dashes. The contrast in the effects of the memory load on the two tasks is apparent.

Performance on the plankton task decreases with increasing

EFFECTS OF MEMORY LOAD
ON STANDARDIZED MEASURES OF
KAYAK CRASHING AND PLANKTON EATING

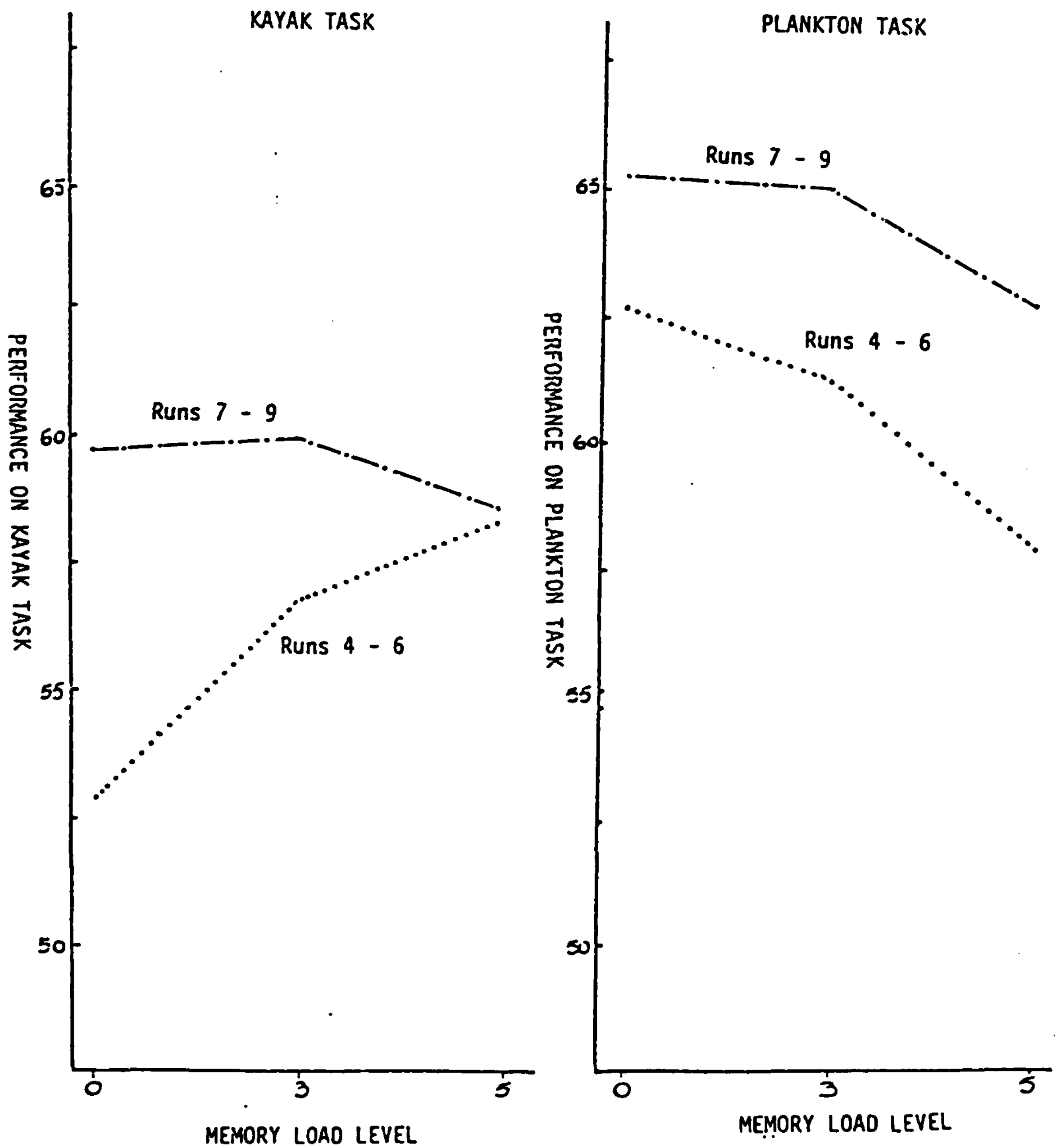


Figure 6-7

memory load. The effects of the two memory load levels appear relatively linear and additive. The improvement from the first to the second group of trials appears to be large but nearly equal across the three conditions.

Performance of the kayak task shows a different pattern. During the first set of experimental trials, performance improved as memory load increased. During the second set of trials, memory load had almost no effect; it is as if subjects were performing with a memory load of 5 letters for all conditions.

Analysis of the within-subjects variance is interesting for several reasons. Priority showed clear and appropriate influences on all performance measures. Omitting the initial practice trials from analysis decreased the main effects of practice and decreased the significance of its interaction with priority. However, the primary focus of this analysis was to identify the effects of memory load. Increases in memory load caused significant decrements in the performance of the plankton task but had no significant effect on the kayak task. The decrements in the plankton task appear to originate in the action system but subsequently are most clearly shown in the motor output system and criterion achievement. Although not statistically significant, the apparent increase in performance of the kayak task with increased memory loads during the initial group of trials is provocative.

6:4 DISCUSSION

At a very general level, this experiment instantiates the approach espoused in the early chapters. Subjects were given a meaningful task and granted a high degree of discretion in determining how to perform it. The extensive measurement enabled

by the microcomputer and multiple analyses demonstrates the capacity to extract empirically useful results from subjects' activities. In fact, the model of the task structure provides an even more powerful explanation of data from this experiment (predicting 62 percent of the variance in the kayak task and 91 percent in the plankton task). Employing better subjects and allowing more practice may both have contributed to the observed convergence between task performance and the representation of its underlying structure.

Closer examination of the raw data identified a slight problem: the bias toward the plankton task during equal priority trials. Although not catastrophic, such a bias weakens subsequent regression analyses and makes interpretation more problematic. Several alternative measures could be employed to ameliorate the bias: 1) adjust the relative number of points during equal priority trials (i.e., replace the 2:1 ratio in favour of kayaks with a 3:1 or even a 4:1 ratio); 2) make post hoc adjustments to the priority coding for the equal trials (i.e., recode "equal" as 2.2 instead of 2.0); or 3) modify the tasks to change their relative effort to performance functions.

Although feasible, the first alternative is awkward to employ and of limited sensitivity. The second option is a post hoc method to compensate for the failure to control conditions sufficiently to elicit truly equal priority. Because the shift is relatively slight, such an adjustment was considered to be unwarranted for this experiment. The third alternative is clearly the best. However, such adjustments are difficult to effect. Several minor changes in the next experiment reflect attempts to re-establish the

desired equilibrium.

An important new instrument was also introduced in this experiment: the espoused strategies worksheet. Demonstrating distinctions between explicit and implicit knowledge (i.e., differences in what people say and do) is awkward. Arguments that observed differences are due to verbal format or simply a failure to ask the "right" questions are ubiquitous and difficult to counter. Establishing criteria for evaluating the validity of verbal protocols is also a problem. To some extent, the employment of equivalent procedures for the two tasks shifts the focus away from the thorny issues of absolute differences between implicit and explicit knowledge toward a consideration of relative differences.

The plankton task involved two rules very strongly correlated with performance. These were obvious (or salient) to subjects and were thus frequently espoused. None of the kayak rules were quite so obvious. However, subjects showed a marked proclivity for both underrating the rules that were important and overrating the least important. The most striking inconsistency is shown by the "line-up" rule. Many subjects rated "turning away from the kayaks" (thus increasing line-up time) as one of the most important rules to follow in crashing kayaks. Measures of line-up time showed consistently negative correlations with kayak crashing. Subjects' explicit knowledge of the kayak task was considerably inferior to their explicit knowledge of the plankton task.

The analysis of individual differences was perhaps the least productive. The results supported earlier findings that subjects who were quicker, brighter and more field independent performed both tasks better. The data contain some evidence that quickness

is slightly more advantageous to performance of the plankton task and incidental learning more beneficial to to the kayak task, but these distinctions are far from clear. The interaction between field independence and incidental learning in predicting the relative strength of the kayak action system (viz., the adherence to appropriate rules) is interesting but requires replication.

It is perhaps too ambitious to expect experiments involving 20 subjects to yield robust and profound results concerning individual differences. It may well be that by granting subjects the freedom to perform the tasks "as best they can," specific individual differences in abilities are obscured by subtle differences in the strategies subjects adopt. The results from the between-subjects analysis are, nonetheless, interesting and generally support other findings.

The most important results are those from the within-subjects analysis. The conclusion that the side task interfered with the performance of the plankton task but not the kayak task is clear. A convincing explanation for this observed difference is not, however, immediately apparent. An explanatory story can be constructed along the lines suggested by the initial chapters of this thesis. The basic tenet of this argument is that the differential effects of the side task reflect structural differences in the tasks themselves and, in turn, the intermediate cognitive processes involved in their performance.

The notion of representing tasks as sets of parameter specification requirements was discussed in the first chapter. In developing the two tasks to be employed in the game, an effort was made to maximize their substantive differences in terms of these

requirements. One task, plankton-eating, involved few parameters and was thus considered more simple than the alternative kayak-crashing task which involved many parameters.

In order to ensure the performance of both tasks would be comparable and relatively free from ceiling and floor effects, compensatory adjustments along a separate dimension (viz., uncertainty) were incorporated. A high degree of uncertainty was generated in the plankton task by relying on complex formulae to produce its psuedo-random "walk" across the screen. Starting the plankton from slightly different initial locations on successive trials contributed further to its uncertainty. In contrast, an attempt was made to ensure the constituents of the kayak task were as "certain" as possible. The arrangement of icebergs was the same for each trial; kayaks were generated from the same locations and at the same time on each trial; and once generated, kayaks always followed the same rule (viz., they moved one space toward the whale).

Although the plankton task involved relatively few parameters, it required these to be specified by reference to external events (i.e., the plankton's position). In contrast, the kayak task required many more parameters to be specified, but allowed (at least some of) these to be specified by reference to internal representations (i.e., mental models) which were derived from the regularities underlying the kayak task.

These two substantively different tasks were coupled with the same side tasks. The side tasks involved the encoding, rehearsal and report of 3 or 5 letters. It was assumed side task performance would involve intermediate cognitive mechanisms (i.e., the

articulatory loop and to a lesser extent the central executive). If these mechanisms are of limited capacity, their employment in one task (i.e., the side task) diminishes their involvement in other tasks (i.e., those involved with playing the game).

From this perspective, the results suggest the intermediate mechanisms involved in performing the side task make important contributions to performance of the plankton task but not the kayak task. This conclusion at first appears somewhat counterintuitive. The a priori predictions of most colleagues as well as the post hoc explanations of many subjects are that because the kayak task is more complex its performance is more dependent on supplementary verbal processing (i.e., self-instruction).

Results from the espoused strategies worksheet provide additional evidence critical to this paradox. If one assumes the articulatory loop only employs explicit (i.e., verbally-coded) material the relevance of inconsistencies in espoused strategies is apparent. For the simple but uncertain plankton task, subjects' explicit knowledge was clearly consistent with their contributory behaviours. However, for the complex but certain kayak task, there was a marked divergence between espoused and implied performance rules. If subjects were telling themselves incorrect or irrelevant things (e.g., "turn away from the kayaks" or "don't eat the icebergs"), occupying their internal speech mechanism with another task might actually improve performance. The provocative initial improvement in kayak crashing with increases in memory load shown in Figure 6-7 might be an example of such a process.

There are clearly a number of alternative explanations, but one in particular deserves consideration. It is possible to conclude

from the prima facie evidence that the primary focus of the interference was on the motor output system and because the plankton task involved (i.e., required) more frequent changes of direction, it showed the greatest decrement. Such a conclusion is, however, contrary to several aspects of the data.

The three conditions involved nearly equivalent amounts of both listening and speaking (i.e., 6 letters every 25 seconds) so there were no differences in overt motor activity. If one argues that it was the subvocal rehearsal causing the interference, the data again provide evidence to the contrary. Subvocal rehearsal was involved in both the 3 and 5 letter memory loads but not the control condition. During both sets of trials, the decrements in plankton-eating performance caused by the initial side task increment (i.e., first 3 letters) is less than the decrement resulting from the subsequent increase in memory load to 5 letters. Also, it seems strange to argue that a modified tracking task (i.e., plankton eating) is structurally similar to subvocal rehearsal. The distinction between manual and verbal response modalities is one of the best supported in the human performance literature (e.g., McLeod 1977, Wickens, 1980).

This alternative explanation also encounters difficulty if one compares the results of this experiment with those of Brown (et al., 1969) presented earlier. Tasks that showed interference (viz. deciding on "possible" gaps and tracking the plankton) and those that were resistent to interference from the verbal side tasks (viz., steering the automobile and crashing kayaks) don't share many obvious similarities (e.g., decision level, relative difficulty, or motor acuity requirements).

There are, however, similarities within these pairs of tasks along the dimensions of complexity and uncertainty. Both tasks which showed interference were relatively simple but uncertain (i.e., adequate performance of either depended on a single, discrete response to an unpredictable occurrence. Although activities involved in steering the car or wrecking the kayaks are both relatively complex, they involve constant relationships. If these relationships are internalized as mental models, task parameters may be specified "automatically" without reliance on limited processing mechanisms. These tasks are thus relatively impervious to interference from other side tasks.

This argument also receives support from Martin's (1982, 1984) studies involving combinations of very similar side tasks with homograph reading. Her finding that although the 3-item memory load increases the temporal delay between the presentation and spoken response for non-dominant senses of homographs, it actually decreases latency (i.e., facilitates performance) for dominant homographs. If one assumes the dominance of the musical sense of "bass" (over either the aquatic or alcoholic senses) reflects differences in knowledge (i.e., the strengths of representational linkages), an interesting parallel emerges. It has been argued that the performance of the kayak task (like dominant senses of homographs) relies more heavily on knowledge to specify required parameters. In contrast, the plankton task (like the non-dominant homographs) require active processing by attentional mechanisms. From this perspective, both the interference with plankton performance and the marginal facilitation of kayak performance appear less unusual.

A FUNCTIONAL EXAMINATION OF INTERMEDIATE COGNITIVE PROCESSES

CHAPTER SEVEN

EXPERIMENT FOUR - REPLICATION, CONVERGENCE AND MODEL MAINTENANCE

7:1 INTRODUCTION

The results of Experiment Three are interesting but the obligation to replicate and the need for convergent support loom large. The opportunity to widen the scope of inquiry and investigate other aspects of the information processing system is compelling. A review of the initial model in the light of Experiment Three's results yields three theoretical distinctions amenable to empirical investigation with the tool and methods being developed; each will be discussed briefly.

Neumann's (1984) notion of different "modes" of information processing is based on the conceptualization of tasks as parameter sets. The two different sources of specification for task parameters reflect the distinction between knowledge and resources. Task parameters can be specified either by reference to extant internal representations or by the active processing of the incoming "flow" of current information. The latter specification mode is more dependent on the availability of limited attentional mechanisms and is thus responsive to shifts in intention and also susceptible to interference from concurrent processing activities. Relatively "automatic" performance reflects subjects' greater reliance on internalized representations of the task's consistent relation structures.

The plankton task was largely random and lacked an accessible, consistent relation structure. In contrast, the kayak

task exhibitted consistent structure relations (i.e., the time and place of kayak appearance and the movement of kayaks once generated were always the same). Thus, the kayak task allowed the development of internal representations and could be performed more automatically than the plankton task. The disappearance of the facilitatory effects of memory load on the kayak task during the second set of trials in Experiment Three is somewhat unusual evidence of such automation. It would be more conventional (as well as convincing) to show significant amelioration of interference with practice as evidence for automation.

Another distinction concerns the functional differentiation of attentional resources into those employed in general processing (i.e., the central executive) and those involved with specific kinds of processing (e.g., the articulatory loop for verbal material). The results of the previous experiment yielded equivocal results concerning the linearity of effects of the different side tasks on performance. The standardized data plots suggested the kayak task benefitted most from the initial increase in memory load from zero to three letters and the plankton task suffered most with the increase from three to five letters. However, no clear statistical evidence emerged to support the hypothesized distinction between the articulatory loop and the central executive. Greater control is required for greater clarity.

Reliance on side tasks which differ quantitatively but not qualitatively introduces a problem. Individual digit-span differences suggest some subjects probably performed even the five-letter side task by employing only the articulatory loop.

Combining data from subjects of different abilities (possibly employing different processes) might obscure differential effects. (The alternatives of simply increasing the load to seven letters or titrating the side task for each subject are fraught with both technical and conceptual difficulties.) In this experiment, an attempt was made to select side tasks with qualitatively different intermediate processing demands to functionally discriminate between the two conceptual components (viz., the central executive and the articulatory loop).

The final theoretical distinction involves the semantic content of the verbal side task and the issue of "encapsulation". In the last experiment, a set of letters, having no obvious relationship to whale game, served as the "contents" for the side tasks. Similarly, digits (i.e., one, two, three, four) are not functionally related to the intermediate cognitive processing required by the game. However, directional words (i.e, left, right, up, down) corresponding to subjects' digital inputs might be relevant to some of the intermediate cognitive processes involved (i.e., self-instruction).

A marked increase in interference with semantically relevant side task contents would imply both a common processing resource and the lack of semantic "encapsulation". The absence of effects, however, would suggest some form of encapsulation. Interactions between contents and side task type would also be of interest in that they would localize the effects in either or both intermediate processing mechanisms.

To summarize, Experiment Four was designed to provide evidence relating to three conceptual distinctions. The first

concerned alternative modes of parameter specification and the issue of automaticity. The prediction was made that the task with the more consistent relation structure (i.e., the kayak task) would show a greater tendency toward automation. The second distinction concerned the functional differences between two types of attentional mechanisms: general and specific (viz., verbal). Based on the differential relative validity of the explicit verbal knowledge relating to the two tasks, a side task involving primarily the verbal resource mechanism should interfere with the plankton task but not the kayak task. A side task involving general resources might interfere with both tasks. Finally the effects of the semantic relevance of verbal contents would reflect the nature of the relationship between processing mechanisms and the information being processed.

7:2 METHODS

Twelve male and twelve female subjects between 18 and 38 years of age from the Oxford Subject Panel individually participated in this two-hour experiment. All were "student or equivalent" and none had participated in any of the previous experiments.

Apparatus was unchanged, but the game had again been modified. One of the main differences involved reducing the fixed processing time from 510 msec to 400 msec and increasing the temporal increment per kayak from 70 to 90 msec. The minimum lag and number of cycles were unchanged, so the net effect was to decrease average cycle time to 669 msec, and the time to complete each trial to 2 minutes 25 seconds.

The iceberg constellations and kayak generation schedule

remained the same for the experimental trials. For the practice trials, however, the constellation of icebergs was modified by moving four icebergs. One explanation for the initial improvement in kayak task performance with memory load in the last experiment is that subjects "unconsciously" followed a set pattern of moves acquired during the practice trials as memory load increasingly occupied attentional mechanisms. Changing the iceberg placement prevented subjects from relying on a specific pattern of moves developed during the practice trials.

Additionally the plankton task was changed slightly. Comparing performance from the two sets of experimental trials in Experiment Three showed performance improved in all conditions with practice. Although subjects' responses to incidental learning questions suggested they possessed little explicit knowledge of the plankton's path, their improved performance implied their internalization of a representation of the route (cf., Pew, 1976).

Plankton had begun each trial from the same area and proceeded in a "north-easterly" direction. In this experiment, the plankton began every other trial by proceeding "south-easterly". Formulae for generating the path were the same so "difficulty" was relatively constant. Altering the global consistency of the plankton's movements "boosted" its randomness and helped widen the substantive differences in the uncertainty of the two tasks.

After completing two 75-trial, 4-choice reaction tasks, adaptive whale training and 6 practice trials (2 of each priority), subjects received side task instruction. Audio-vocal side tasks were again selected to minimize interference caused by peripheral similarity. Two different verbal side tasks with different sets of

contents were employed. Each set of contents contained four single syllable words. "One", "two", "three", and "four" comprised the control set and "left", "right", "up", and "down" made up the semantically-relevant set. These four directions corresponded to the function of the four control keys.

Two different verbal side tasks required subjects to produce responses in time to a mechanical metronome at a pace of one response every 1.5 seconds. The two side tasks differed only in the order in which subjects were to produce their responses. In the simple articulatory suppression condition, subjects produced responses in a fixed order (e.g., "1,2,3,4,1,2..."). It was assumed this task would involve only the articulatory loop.

In contrast, the other side task placed greater demands on general processing resources (i.e., the central executive). For this task, subjects were required to produce responses in a "random" order (Baddeley, 1966). Before attempting this, the concept of randomness was discussed and practised. Subjects were told that randomly-generated sequences should have approximately equal frequencies of each of the possible responses, there should be an equal frequency of the 16 possible "digrams" (conditional probabilities) and trends should be counterbalanced. Subjects provided 100 responses in time to the metronome, first with numbers then again with directions. As each of the subjects responses was produced, it was input to the Spectrum computer by the experimenter. At the completion of each practice, the computer displayed a data table reflecting each of the randomness criteria discussed for the sequence of responses the subject had just produced. All subjects were familiar with the concept and

simulation of randomness.

After a short break, each subject completed 18 trials (6 of each of the priorities in rotation). For each of the three priorities, two of the six trials involved no verbal side task (a pure control), two involved simple articulatory suppression and two involved randomized articulatory suppression. One of the two trials of each priority (with each of the side tasks) required "numeric" responses and the other required "directional" responses. Thus, each subject completed each of the possible combinations of priority, side task type, and contents. Order of presentation was counterbalanced across the 24 subjects. At the end of each trial, subjects recorded their scores on both sub-tasks from the monitor display and were told their "randomness" score by the experimenter as appropriate.

A partial measure of randomness (based only on the relative frequency of the four responses in the content set) was computed as subjects played the game. This measure (1.0 less the frequency difference between the most and least common responses divided by total responses) was obtained from a TRS-80 Pocket Computer. (The Spectrum was occupied by the subject playing the game.) The primary purpose of this was to remind subjects of the importance of producing random sequences continually. Although this score did not include conditional probabilities or trend information, any deviations noted were identified to the subjects.

Subjects' score sheets were annotated to show the priority, side task type and contents for each trial. Each successive set of three trials required subjects to complete each of the three priorities - one with no side task, one with articulatory

suppression alone and one with randomized articulatory suppression (the contents of one of the side tasks were numbers and the other directions). One male and one female subject completed each of 12 counterbalanced presentation schedules. After the final trial, subjects were debriefed and paid. None of the individual difference instruments were administered.

7:3a GLOBAL ANALYSES

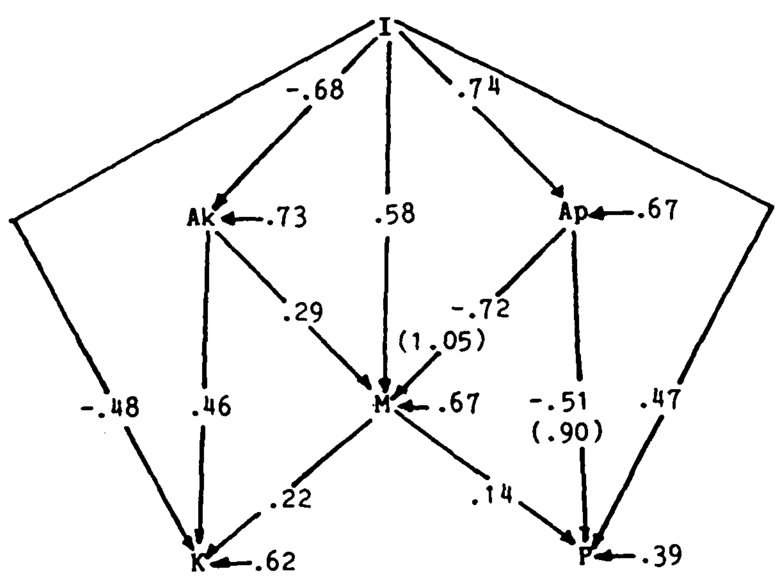
The two most important changes were the introduction of a qualitatively more demanding side task and the 10 percent increase in the game's pace. Some performance measures appeared to be relatively impervious to these alterations while others showed marked decrements. Intention, the components of the kayak action system and the kayak criterion were virtually unchanged from the previous experiment. In contrast, the plankton action system, number of direction changes and plankton criterion all decreased. Compared to the last experiment, the number of direction changes decreased 14 percent. However, the rate of directional changes (i.e., average time between changes) increased by only 3 percent (from every 2.17 seconds to every 2.24 seconds). The increased pace thus appears to have a greater impact on the effectiveness of subjects' responses rather than on the rate at which responses are produced. Further analysis shows this more clearly.

Measures were taken of the relative timing of subjects' control inputs within each cycle. Basically this involved reading the keyboard 150 msec before the computer accepted the "operative" input. A comparison of the value of this early reading with the actual input showed the number of times changes were effected in

DESCRIPTIVE STATISTICS, ZERO-ORDER CORRELATIONS AND TASK STRUCTURE FOR EXPERIMENT FOUR*

Variables**	I	Ak	Ap	M	P	K	IBE	CEN	LUT	QST
Mean	73.3	4.95	.299	64.6	11.1	9.4	3.76	99.9	70.5	.78
SD	47.7	2.09	.130	12.7	10.8	3.9	2.50	41.3	14.1	1.28
I		-.68	.74	.59	.82	-.65	.01	-.74	.18	-.51
Ak			-.51	-.23	-.55	.73	-.04	.75	-.66	.68
Ap				.55	.76	-.45	-.00	-.54	.09	-.44
M					.71	-.16	-.01	-.26	-.03	-.25
P						-.50	-.01	-.60	.13	-.43
K							-.13	.69	-.48	.36
IBE								.08	.08	-.08
Cen									-.25	-.32
LUT										-.13

TASK STRUCTURE



* N= 576 (24 subjects X 24 trials)

**Variables: I= Intentions (less than three spaces); Ak= Kayak Action System (centre, not lined-up, one quadrant); Ap= Plankton Action System (one space percentage); M= Motor Output System (changes of direction); P= Plankton eaten; K= Kayaks destroyed; IBE= Icebergs eaten; LUT= Line-up time; QST= Commitment to one quadrant strategy.

Figure 7-1

the last 150 msec of the cycle. Such changes were assumed to reflect "good timing". For Experiment Three, subjects' average number of these "last chance" changes was 21.1 (SD = 10.3) or 28 percent of their 74.8 directional changes. During Experiment Four, subjects made 17.4 (SD = 7.0) such changes. These represented 27 percent of subjects 64.6 directional changes. Thus, it appears the effects of the increased pace were not localized in the motor output system. This suggests the involvement of intermediate cognitive processes.

One of the problems identified in the last experiment was the bias toward the plankton task during the equal priority trials. The net effect of the quickened game pace and increased uncertainty of the plankton path resulted in a shift toward the kayak task. In fact, there was a slight (3.7 cycle - .08 SD) bias toward the kayak task during equal priority trials.

The correlation matrix is very similar to those presented earlier. Intention has similarly strong relations to both action systems. The differential significance of the three rules which comprise the kayak action system is more apparent. Staying in the central region (r=.69) is clearly the most important. Although, it is helpful not to turn away from the kayaks (r=-.48) and stay in one quadrant (r=.36), these are less effective. As previously observed, eating icebergs is nearly irrelevant to criterion achievement.

The task structure depicted in Figure 7-1 is also familiar. The hierarchic framework again receives general confirmation. Together with similarly supportive results from the previous experiment, this suggests the efficacy of the model increases with

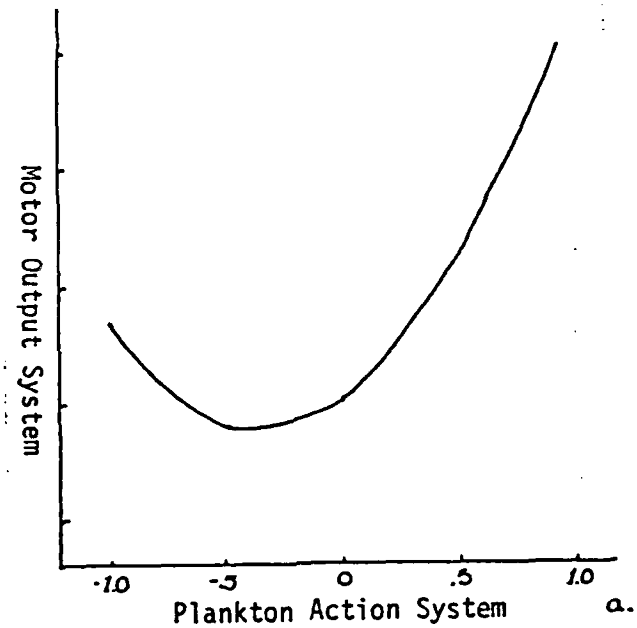
the number of trials and subjects' abilities. This convergent tendency suggests the model captures important emergent aspects of the game's underlying relation-structure. The better the performance, the more closely it adheres to the depicted model. The curvilinear relations between the plankton action system and the motor output system and plankton criteria (shown in Figure 7-2 a and b) are nearly the same as those encountered in earlier experiments. These seem to be relatively enduring characteristics of the underlying relation structure. All other predicted paths are in the appropriate direction and meet the criterion for retention (computed t greater than 5.00).

It is interesting that the zero-order linear correlation between the motor output indicant and the kayak criterion are consistently lower than those between the motor output system and the plankton criterion. However, once the effects of intention and the respective action systems are taken into account, the motor output system adds more to the explanation of kayak crashing than plankton eating. The motor output system indicant largely replicates the plankton action system information. In contrast, it contains very little of the information of the kayak action system indicant. This might be depicted in the task structure by shifting the plankton action system downward to a level closer to the motor output system. The model is not impeccable, however, by providing an account for 62 percent of the variance in the kayak task and 85 percent in the plankton task, it has again demonstrated its descriptive utility.

7:3b BETWEEN-SUBJECTS VARIANCE

In order to concentrate on the influences of the experimental

DEPICTION OF CURVES INDICATED
IN EXPERIMENT FOUR TASK STRUCTURE



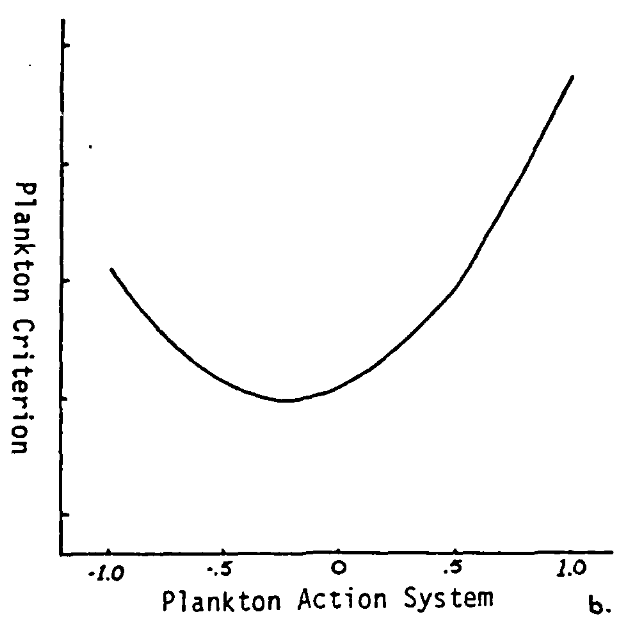


Figure 7-2

conditions, no individual difference measures were taken. Consequently, between-subjects analyses were not accomplished for this experiment. More extensive within-subjects analyses help compensate for this deficit.

7:3c WITHIN-SUBJECTS VARIANCE

Regression equations are shown in Figure 7-3. The portion of the variance explained (R^2) for most variables is much greater than previously. Apparently the increased load placed on subjects by the faster game pace and more demanding side tasks combined to constrain performance naturally. Whatever the cause, the consequence is important. The greater the proportion of variance explained, the more statistically significant influences of a particular effect size become. The larger R^2s imply considerable improvement in the resolution of the regression analyses.

This experiment contained five separate influences: priority, practice, articulatory suppression, randomization and the semantic contents of articulation. In addition to the main effects, curvilinear influences and nine potential two-way interactions were inspected. The semanticity of contents did not have a significant main effect, nor did it interact with any of the other variables to explain a significant portion of the variance in any of the dependent measures. An inspection of its main effects suggested directions (in contrast to numbers) interfered slightly with plankton performance but slightly facilitated performance of the kayak task. However, the size of these effects was only about one quarter as large as the effect of articulatory suppression and one tenth the size of randomization's effects. In order to preserve the significance of the other variables and simplify the equations,

REGRESSION EQUATIONS SHOWING WITHIN-SUBJECTS INFLUENCES
ON SELECTED PERFORMANCE MEASURES
FOR EXPERIMENT FOUR

Intention =11.60 PRI +.37 RUN -.22 ASP -1.06 RDZ +25.84
t(342) = 47.08** 3.22** -.45 -2.15*
R^2 = .87 F (72,342) = 31.79**

Pkt Act Sm =19.45 PRI +2.65 P^2 +.44 RUN -1.27 ASP -3.00 RDZ +22.90
t(324) = 6.24** +3.44** 2.01* -1.43 -3.38**
R^2 = .57 F (90,324) = 4.77**

Kyk Act Sm =-15.82 PRI +1.60 P^2 +.26 RUN +.01 ASP -1.76 RDZ +72.22
t(324) = -5.68** 2.32* 1.37 .01 -2.22*
R^2 = .64 F (90,324) = 6.40**

Centre Reg =-9.41 PRI -.21 RUN -.99 ASP -6.20 RDZ +.96 RXR +70.11
t(324) = -22.12** -.83 -1.16 -2.45* 2.20*
R^2 = .60 F (90,324) = 5.40**

Quad Stgy =-6.41 PRI -.48 RUN +.96 ASP -1.43 RDZ +65.55
t(342) = -11.36** -1.81 .86 -1.27
R^2 = .30 F (72,342)= 1.93**

Drct Chngs =6.67 PRI +.61 RUN -4.16 ASP -6.93 RDZ +38.27
t(342) = 13.23** 2.48* -4.08** -6.80**
R^2 = .40 F (72,342) = 7.13**

Pkt Eaten =7.80 PRI -.48 RUN +.52 RXP -2.02 ASP -4.36 RDZ +34.36
t(324) = 6.78** -1.10 2.66** -2.93** -6.32**
R^2 = .76 F (90,324) = 11.40**

Kyk Crshs =-9.50 PRI +.43 RUN -.42 ASP -6.97 RDZ +.94 RXR +67.30
t(324) = -24.30** 1.87 -.53 -2.97** 2.34*
R^2 = .65 F (90,324) = 6.69**

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* p < .05 ** p < .01

Independent Variables:

PRI - Priority instructions (1- kayaks; 2- equal; 3- plankton)
P^2 - Curvilinear effects of priority instructions (PRI^2)
RUN - Amount of Practice in 3-trial increments (3 through 8)
RXP - Interaction between priority and practice (RUN*PRI)
ASP - Articulatory suppression in fixed sequence (1,0)
RDZ - Randomized articulatory suppression (1,0)
RXR - Interaction between practice and randomization (RUN*RDZ)

Figure 7-3

semanticity of contents was omitted. The effects of the remaining influences will be discussed separately.

In spite of the demanding side tasks, the effects of priority remained ubiquitous and pre-eminent. All measures of performance strongly reflected the instructions subjects were given. The priority coefficient for the measure of intention (Bp = 11.60) implies that, with shifts in instructions, subjects adjusted their proximity to the plankton by more than a full standard deviation.

Both action systems show small but significantly non-linear effects of priority in addition to strong main effects. Closer examination of these relationships shows that for both action systems, the greater increases occur when priority for their respective tasks increases from equal to high. In both cases, however, the relative amount of curvature is small. Two of the rules associated with kayak crashing show significant linear relationships with priority for kayaks, but line-up time and icebergs eaten again showed no consistent relationship to any of the independent variables. Priority also had significant linear influences on both criteria and again showed a significant interaction with practice for plankton eating.

The effects of practice are interesting. For the first time the measure of intention shows a positive effect of practice. Although the size of the effect (Br = .37 implies a .04 SD increase with each run) is small, the large R^2 (.87) makes this statistically significant. It is possible staying within three spaces required a modicum of skill as well as raw intent due to the increased game speed. However, a comparison of effect sizes suggests the influence of priority is over 10 times as great as

that of practice.

Once again the number of directional changes shows the largest (if not most significant) effect of practice (Br = .61). The unique, significant interaction between practice and priority is replicated for the plankton criterion. This suggests the effects of practice on plankton performance are directly mediated by priority instructions (and presumably subjects' intentions).

The coding of the two experimental conditions (i.e., simple articulatory suppression (ASP) and randomized articulatory suppression (RDZ) provides contrasts between each condition and the control. To compute regression predictions for each variable in the control condition the values of ASP, RDZ and RXR would each be zero. Predictions for simple articulatory suppression are derived by setting RDZ and RXR to zero and the value of ASP to one. For the predictions under the randomized condition, ASP is zero and RDZ is one. The value of the interactional term is simply the same as the appropriate RUN (i.e., 3 through 8). These influences will be discussed separately.

In the simple articulatory suppression condition, subjects made verbal responses in time to a mechanical metronome in a fixed order. Half the responses involved numbers and the other half directions but, as discussed previously, contents did not have a significant influence. Simple suppression only had significant effects on two performance measures; the number of directional changes and the tonnes of plankton eaten. There were, however, no significant interactions between simple articulation and either priority or practice. The decrease in the number of directional changes associated with simple articulatory suppression appears to

be relatively constant across all conditions but most significant at the motor output level.

In contrast to the relatively focussed effects of simple articulation, randomization interferes with nearly every measure of performance for both tasks. Randomized suppression had the least effect on intention (B_{a_r} = -1.06) but again the high R^2 renders the effect significant. Randomization caused significant decrements in both action systems but appeared to have the greater effect on the plankton action system. In fact, the only non-significant effect of randomization involved subjects' employment of the one quadrant strategy. Interference from randomization is most strongly reflected, however, in the motor output system and achievement of both criteria. Although randomization has very general effects, the magnitude of these effects consistently increases as the hierarchic level decreases.

There is another important aspect of the effects of randomization; significant interactions with practice for two of the variables (viz., staying in the central region and crashing kayaks) emerge. These interactions imply that with practice, subjects were increasingly able to isolate performance of the kayak task from the interfering effects of producing responses in random sequences. It is interesting to note that although staying in the central region was objectively the most important of the trio of rules comprising the kayak action system, its espoused rating was nearly neutral.

Again it is useful to compare performance of the criteria under conditions when each was to be given priority. Figure 7-4 contains these plots for the two tasks. Each data point represents

EFFECTS OF SIMPLE AND
RANDOMIZED ARTICULATORY SUPPRESSION
ON STANDARDIZED MEASURES OF
KAYAK CRASHING AND PLANKTON EATING

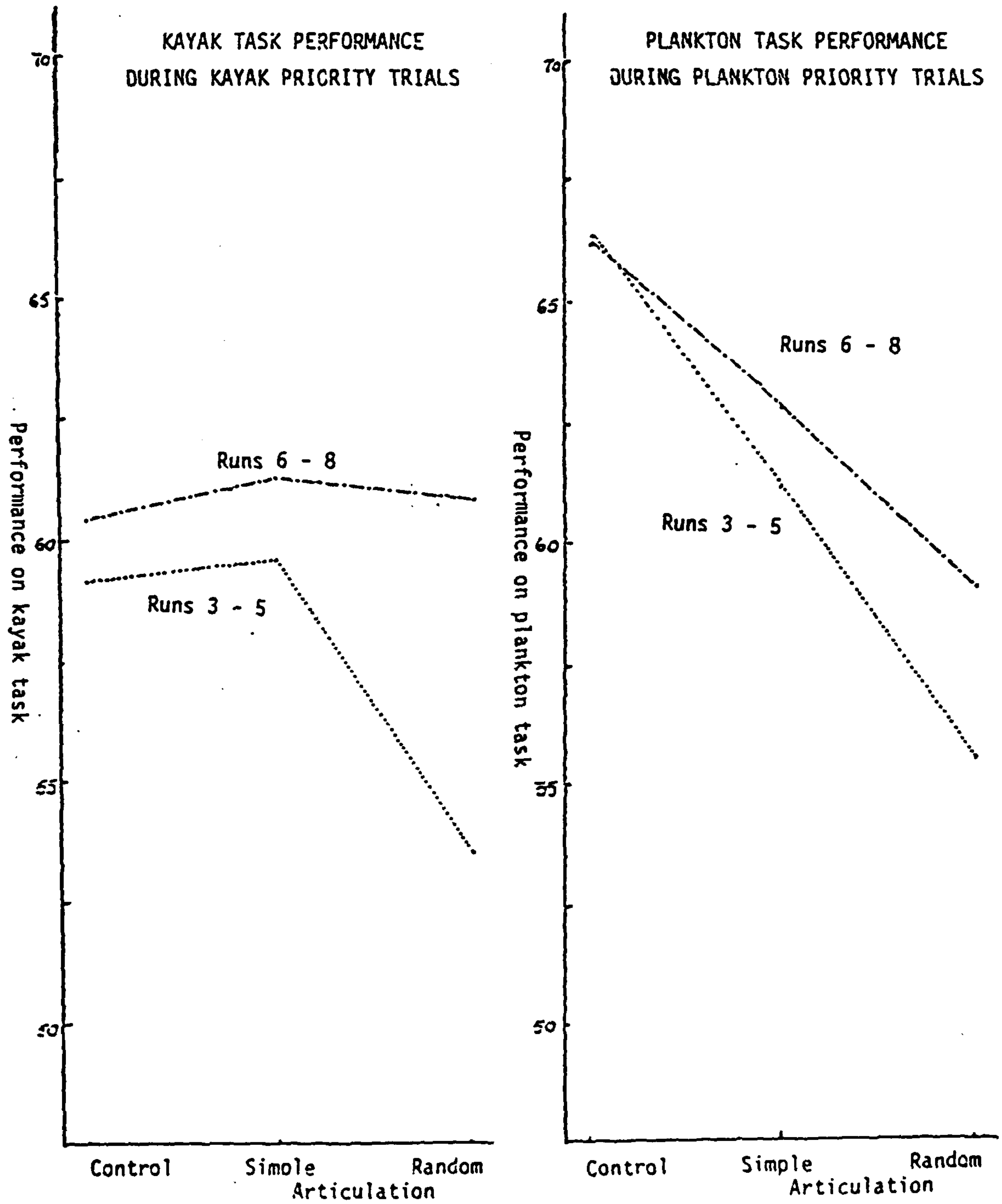


Figure 7-4

the average standardized score of all 24 subjects. Half the subjects in each case were using numbers and the other half directions. Performance points during the first set of experimental trials (runs 3 through 5) are connected by dotted lines and performance during the second set (runs 6 through 8) by alternating dots and dashes.

Several of the effects discussed previously are clearly represented by the performance plots. The differential effect of simple articulatory suppression on the two tasks is readily apparent at both levels of practice. Plankton performance showed marked decrements, but kayak performance showed slight improvement. During the first set of experimental trials, the effect of randomized articulatory suppression on the two tasks is indistinguishable (i.e., the slopes of the lines connecting simple and randomized suppression are virtually identical). However, during the second set of trials, the contrast between the effects on the two tasks is striking. Although randomization interference has decreased slightly for the plankton task, it has disappeared altogether for the kayak task. Compared to the control conditions, subjects performed the kayak task slightly better when producing paced random responses. The effects of simple and randomized articulation appear linear and additive for the plankton task. For the initial set of trials with kayak priority, there is a clear discontinuity in the two effects.

Several contrasts with the performance graphs presented in the last chapter are interesting. There is little evidence of the initial improvement in kayak performance shown with increased memory load. The improvements in plankton performance during

control conditions observed in the past experiment did not recur. Although these may both be coincidental, they are consistent with the objectives of the game modifications presented earlier (i.e., using a different iceberg constellation in practice and altering the initial direction of plankton movement).

The greatest improvements from the first to the second set of trials occurred in the randomized suppression condition. Analyses of the partial measure of randomness described earlier did not show significant influences of either practice or priority. It is therefore assumed that the investment of intermediate processing resources in side task performance was the same for all conditions.

7:4 DISCUSSION

This experiment involved the fastest pace and most demanding side tasks. However, better subjects and more practice than in the two initial experiments offset any general negative effects. Performance remained in a range comparable to the other experiments. Although the faster pace appeared to diminish the effectiveness of responses for the plankton task, the average rate and timing of responses were virtually unchanged. One beneficial consequence of this disproportionate impact on the plankton task was that performance during the designated equal priority trials was much closer to parity. The bias toward plankton noted in the previous experiment was eradicated. The restoration of relative equality may have subsequently enhanced the explanatory power of the within-subjects analysis.

Before addressing the conceptual issues presented at the beginning of the chapter, it is worthwhile to comment on the apparent effects of two peripheral game modifications. One of

these concerned the plankton's path and the other the iceberg constellation. On alternative trials, the plankton's initial direction of travel switched from "north-easterly" to "south-easterly." The improvement in plankton performance in the control condition observed in the last experiment was not replicated. Alternatively, the slight improvement in plankton performance across the other five conditions from this experiment and the last, might suggest the marginal automatization of the side tasks themselves. The lack of improvement in the pure control employed in this experiment shows the plankton task's resistence to automation. This lack of improvement is not due to ceiling effects;optimal performance would be +3.73 SD. Such resistance to automation is consistent with the task's inherent uncertainty and consequently the mandatory involvement of limited-capacity processing mechanisms.

By altering the constellation of icebergs during the six practice trials, subjects were prevented from developing and then employing a specific pattern of responses for dealing with kayaks. To some extent, reducing the number of practice trials from nine to six would have a similar effect. Whatever the reason, the initial improvement in kayak performance with increased memory load was not replicated by these data. This suggests internalization of a set pattern of responses may have contributed to the initial improvement observed in the last experiment. It is also possible the memory load and paced articulation side tasks simply involved different intermediate processing demands. The most important results, however, involve the conceptual issues proposed initially.

The significant interaction between randomization and

practice in the kayak task contrasts sharply with the slight improvement in the plankton task. This is consistent with the initial prediction based on the relative certainty of the relation structures underlying the two tasks. Assuming randomization continued to involve general intermediate processing resources (as Baddeley (1966) and the analysis of the partial scores of randomness suggest), the lack of interference in kayak performance must be attributed to its automatization. Staying in the central region (a largely implicit rule) showed a similar significant interaction between practice and randomization. Subjects were often quite surprised that their performance on the kayak task showed no decrement or even improvement with randomization. Because the plankton task lacked an accessible relation-structure, the extent to which it could be automated was much less.

The general effects of the randomization side task themselves are interesting. Nearly every measure of performance showed significant decrements when subjects were required to produce responses in "random" sequences. However, from this pervasive interference, several patterns emerge. The first of these provides convergent support for the validity of the measures and their hierarchic structure. The effect size (in standard terms which allows the comparison between measures) generally increases at each successive level (i.e., from intention to action to motor output system and finally performance). This apparent cascade of effects is consistent with decrements being "passed on" to each successive level, culminating in the greatest interference occurring in criterion achievement. The similarity of the interference caused in the two tasks during the initial set of experimental trials is

striking. Assuming the randomization task truly involves a "central executive," the evidence is strong that such a processing component contributes equally to the performance of both tasks initially.

The effects of the simple articulatory suppression side task are very similar to those produced by the memory loads in the previous experiment. Superficially at least, suppression and memory load cause nearly the same decrements in the plankton task and leave performance of the kayak task unaffected. A strong argument was made against attributing the decrements observed in the last experiment to mere motor interference. Unfortunately, the same argument does not necessarily apply to these data. There is, in fact, reason to suspect that response competition (i.e., the difficulty in simultaneously initiating responses in different modalities) may contribute to the interference caused by simple articulatory suppression. One difference between suppression and the control condition was the overt verbal responses. Although such an activity interfered with the intermediate portion of the articulatory loop, it also may have had direct effects of its own (i.e., as might tapping one's foot). In retrospect, such a side task would have served as an ideal control. Any decrements caused by interference with the articulatory loop are confounded by the direct decrements caused by response competition. Thus although superficially similar to the results of the previous experiment, this experiment offers little additional evidence of the differential effects of the articulatory loop on the two game tasks.

The effects of the semantic contents were in the right

direction to be consistent with the previously hypothesized differential effect of the articulatory loop on the two tasks (i.e., the employment of directions interfered with the plankton task but facilitated performance of the kayak task). However, the size of these effects was very small. There are several alternative explanations for this lack of effects.

The popular claim that the information processing system is essentially modular and parallel in structure is consistent with these data but unnecessary. Subjects may have been able to directly "encapsulate" the semantic contents of the words employed. Although "left", "right", "up" and "down" correspond to the directional controls subjects employed, in other contexts they might individually be interpreted as the past tense of a verb, a noun denoting an entitlement and adjectives describing moods. In the context of the side tasks, these words could have been treated simply as distinctive phonemes. Subjects were relatively certain at the beginning of the trials that directions would be much more "difficult" to employ than numbers. Their performance suggests they were as incorrect as the experimenter.

This lack of semantic effect might also be taken as evidence the contribution of self-instruction to performance of the plankton task did not involve specific directional information. This is reasonable; on average subjects had about 500 msec to input appropriate responses from the time the plankton was presented in a new location. Specific directional mediation through internal verbal mechanisms does not seem feasible in such circumstances. Perhaps, the contribution of the articulatory loop to performance of the plankton task was more general. The role of the verbal

homunculus may be closer to that of a cheerleader than an expert technical advisor. If this is true, numbers and directions would both be semantically irrelevant.

To summarize briefly, this experiment provides strong support for the diffential automatability of the two tasks. The certain kayak task, despite its greater complexity and subjective difficulty, comes to be performed relatively automatically with a little practice. In contrast, the simple, subjectively easy but deceptively uncertain plankton task is very resistant to automation. Although the involvement and generally pervasive initial contributions of the central executive are clearly shown, evidence concerning the articulatory loop is confounded by the direct effects of motor activity. Observed decrements in the plankton task and the lack of effects on the kayak task are similar to those of the last experiment but do not provide independent convergent support. There was little evidence that the differential semantic contents affected performance. This could be due to the "encapsulation" of information being processed or simply to the equal irrelevance of both numbers and directions. Several of these issues will be adressed in the next experiment.

CHAPTER EIGHT

EXPERIMENT FIVE - REBUTTING ALTERNATIVE EXPLANATIONS

8:1 INTRODUCTION

In Chapter One, care was taken to distinguish conceptually between intermediate cognitive processes and peripheral functions (i.e., the acquisition of stimulus information or the execution of selected responses). The view adopted in this thesis is that the unique function of intermediate cognitive processes is the specification of task parameters. Three separate potential sources of specification were presented. Parameters can be specified directly by reference to extant internal representations of consistencies underlying the task structure (i.e., implicit knowledge). Task parameters not specified in this way require active processing by agnostic, limited-capacity attentional mechanisms.

Two types of active processing mechanisms were distinguished: general and modality-specific. Baddeley and Hitch's (1974) model of working memory includes both. The central executive is a general-purpose processing resource and is assumed to "control" a number of slave mechanisms (e.g., the articulatory loop and the visuo-spatial scratch pad). General, central-executive type resources can be involved in the operation of specialized slaves but each slave mechanism is domain-specific. For example, the articulatory loop can process only verbal (ergo, explicit) information. Although there may be many specialized mechanisms (Gardner (1983) suggests seven), only the articulatory loop has been considered separately by the experiments in this thesis.

Central executive processing, therefore, includes contributions from all the interactions between general processing resources and specialized mechanisms other than the articulatory loop.

Once a task's parameters are specified (i.e., the intended response is selected), necessary motor activities are accomplished by peripheral motor output systems. Thus motor activity can be viewed as the product of three separate influences: implicit knowledge and two types of intermediate cognitive processing (viz., verbal and non-verbal). (Although slave mechanisms may enjoy priveleged connections with different sensory or response modalities, it is the intermediate functions of these mechanisms that is of greatest interest here.) Before presenting the methods and procedures to be employed in Experiment Five, it will be useful to review briefly the procedures and results of the two previous experiments in terms of this conceptual model.

In Experiment Three, different levels of a verbal memory load were introduced as side tasks after subjects had practised the game for approximately 30 minutes. The control condition involved the same amount of overt articulation as the two experimental conditions. The difference in the experimental conditions was the number of different items in the random sequence of letters to be remembered.

The memorial side tasks interfered with the performance of the plankton task but not the kayak task. The results also showed asymmetrically non-linear memory load effects on the two tasks. The initial increase of three items had a positive effect on kayak task performance. The increase from three to five items had no effect on the kayak task but showed the greatest interference with

the plankton task.

In Experiment Four, the difference in side tasks was qualitative rather than quantitative. One side task involved the production of four responses in a fixed order. The other side task required subjects to produce the same responses in a random order. The type of items to be articulated also differed; one set of items was sematically irrelevant to the game (viz., numbers) and the other set potentially more relevant (viz., directions). The control involved no side task. Responses for both side tasks were made in time to a mechanical metronome at a rate of one response every 1.5 seconds.

While the two side tasks produced additive and nearly identical amounts of interference in the plankton task, only the randomized side task interfered with the kayak task. Although practice tended to ameliorate side task interference for both game tasks, by far the greatest change was shown by the complete obliteration of the negative effects of randomization on the kayak task. The articulatory contents were relatively unimportant.

In terms of the theoretical model (and Baddeley and Hitch's (1974) formulation), both memory loads employed in Experiment Three, involved the articulatory loop. However, the longer (5-letter) string required more involvement of the central executive. The paced, fixed-sequence articulation side task used in Experiment Four was developed to specifically and exclusively involve the articulatory loop. The randomized side task involved both the central executive and articulatory loop. Thus fixed-sequence production blocked contributions from the articulatory loop. Differences between fixed and randomized

articulatory suppression showed the effects of also blocking contributions from generalized, central-executive type resources.

These results have several implications. The most demanding side task (i.e., randomized articulatory suppression) initially caused nearly identical interference to both game tasks. This suggests, the central executive contributed to both plankton-eating and kayak-crashing.

Although the 5-letter memory load may have required the involvement of more general resources than the 3-letter load, it still strongly involved the articulatory loop. The 5-letter load was situated on the conceptual boundary between the articulatory loop and the central executive. From this perspective, the strong interference with the plankton task suggests the additive positive effects of the two influences.

The apparent lack of effect of memory load on the kayak task might reflect either insensitivity or the cancellation of opposite effects (i.e., the central executive contributed to kayak performance but the articulatory loop's influence was negative). Results suggesting the relative inconsistency between espoused strategies (the most likely occupants of the articulatory loop) and efficacious strategic behaviours provide convergent support for the latter interpretation.

Paced, fixed-sequence articulatory suppression involved the articulatory loop and caused interference with the plankton task but did not interfere with performance of the kayak task. Similarly, the 3-letter memory load caused decrements in performance of plankton task but not the kayak task. In fact, the influence of the 3-letter load during the first set of experimental

trials was positive.

Some aspects of these results are rather counter-intuitive. The plankton task responds in a very predictable and consistent manner (i.e., everything seems to interfere to a degree approximately commensurate with the level of side task demand). The influences of the same side tasks on the performance of the "more difficult" kayak task are quite contrary to the predictions of most subjects and laypersons as well as many experimental psychologists. There are several explanations which might fit the data without recourse to the alternative parameter specification model offered by this thesis. Two of these will be presented.

It is possible the observed effects all reflect differential responses to side tasks based on subjects' misperceptions of the relative demands of the game tasks. As the "difficulty" ratings of the priority conditions suggest, subjects almost unanimously nominated the kayak task as being more difficult than the plankton task. Believing this, subjects might have garnered more "resources" when asked to combine a particular side task with the kayak task than when asked to combine the same side task with the plankton task.

From this perspective, the lack of interference with the kayak task reflects the positive contributions of the additional resources. Alternatively, the decrement in performance on the plankton task shows what happens when subjects "get caught with their resources down" (i.e., because they assumed the task was easier, they didn't allocate sufficient extra resources or effort to perform the task combination). From this perspective, the single side task which interfered with the kayak task was the only

true overload condition (i.e., even when all available resources are allocated to the tasks, subjects could not perform the game tasks at the control level). The other decrements in performance of the plankton task might be artifactually based on subjects' misperceptions of task difficulty.

A similar alternative explanation rests on the apparent differential dependence of the two game tasks on the number of subjects' overt responses (i.e., changes of direction). Performance of the plankton task is more clearly associated with more responses as shown by the number of directional changes and the level of plankton criteria achievement (the average correlation between the two across all experiments is .73). If one assumes the main inluence of most of the side tasks occurs in the motor output system rather than intermediate cognitive processing, the greater dependence of plankton performance on the number of directional changes accounts for many of the results. Although an argument against this possibility was presented in Chapter Six, this alternative was largely ignored in last experiment. No direct measure of the size and focus of motor interference has yet been made.

Both previous experiments considered performance only after subjects had completed several practice trials. In Experiment Three, subjects were allowed nine trials of practice with exactly the same version of the game as was subsequently employed in the experiment. In Experiment Four, they were allowed six practice trials with a slightly modified version of the game. In both cases, however, performance was observed in the context of potentially positive influences from implicit knowledge. The key

relationship between the whale's position and the kayaks' movement was constant and presumably already internalized by the time subjects began the experimental trials. The contributions of intermediate processing mechanisms (i.e., both articulatory and general) in the absence of positive inputs from implicit knowledge were not examined.

This experiment will deal with the three issues just presented. The first is the extent to which subjects' performance is mediated by their intentional allocation of resources in response to perceived increases in task demands. The second issue concerns the focus and magnitude of interference from motor activity (with minimal involvement of intermediate processing mechanisms). The final question involves the relative contributions of active attentional mechanisms in the absence of viable implicit knowledge structures.

Donald Norman suggests time is the "universal resource" and may be usefully employed by all active information processing activities. The game itself already involved a certain amount of temporal variability (caused by the additional processing time for each kayak present during a particular cycle). None of the previous 84 subjects had, however, spontaneously reported this intra-trial variance, and several who had been explicitly asked if they noticed claimed ignorance. In contrast to the side task conditions, time appeared to be an ideal way to covertly manipulate the availability of resources on a trial-to-trial basis. While time discriminates the contributions of active processing mechanisms from the passive influence of implicit knowledge, it does not differentiate between verbal and non-verbal intermediate

processes; the effects are simply combined.

The second issue involved the direct interference caused by motor activity. In previous experiments, care was taken to ensure each of the verbal side tasks involved intermediate rather than just peripheral aspects of the articulatory loop. For the memory load, changing the string to be rehearsed every 25 seconds prevented "overlearning". Likewise, the requirement to produce verbal responses in time to a metronome required the combination of information from explicit knowledge (the correct response) and the environment (the precise timing of the metronome's click).

It was feared the more usual practices of employing a single string of letters as the memory load for the entire trial or having subjects produce unpaced responses might allow subjects to relegate side task performance to the peripheral motor mechanism. One way to discredit the alternative explanation involving motor activity interference would be to directly test the fears just enumerated (i.e., allow subjects to produce unpaced, fixed-sequence, overlearned verbal responses throughout the game trials). Such a task was employed on alternate trials in this experiment.

The third issue involved the contributions of intermediate cognitive processes in the absence of directly-relevant implicit knowledge structures. To address this issue, experimental manipulations (i.e., time and peripheral suppression) were imposed from the beginning of the game. This allowed all trials to be analysed together. Significant shifts in the contributions of processing resources (shown by the effects of time) with the development of implicit knowledge (shown by the level of practice) would be reflected by interactions between the two. The lack of

interactions would suggest the relative independence of the two influences.

Another purpose of Experiment Five was to replicate the results of the between-subjects analyses from Experiment Three. The specific effects of individual differences as well as the subjects' ratings of the different priority conditions and espoused strategies were of interest.

8:2 METHODS

Again, 12 male and 12 female "student or equivalent" subjects, who had not previously participated in any of the studies, took part in this two-hour experiment. Because of difficulties in scheduling subjects, regular subject panel members were augmented by seven fellow graduate psychology students. The apparatus remained the same (i.e., a 48K Spectrum microcomputer with twin ZX Microdrives, a ZX Mini-printer and a 16 inch colour monitor).

The game was the same as used in Experiment Four (i.e., the iceberg constellation, kayak generation schedule and plankton paths). The only difference in the game was the temporal manipulation. A pause of 0, 45 or 90 msec was embedded within the "fixed" processing time (just before the computer accepted subjects' keyboard inputs). The minimum lag time of 160 msec and kayak increment of 90 msec were the same for all conditions. The average cycle times for the conditions were 671 msec, 711 msec and 760 msec (i.e., "fast", "medium" and "slow"). Subjects were not told about the temporal variance and post-task questioning indicated they had no awareness of different trial speeds.

General procedures were similar to those employed previously

but differed in several ways. After completing the two 75-cycle, 4-choice reaction tasks and performing the whale training (i.e., achieving the performance criterion of 10 laps around an iceberg in under 70 seconds), the verbal side task was introduced. This involved unpaced articulatory suppression with the directions "left", "right", "up" and "down". Subjects were told to articulate a repetitive series of the four directions at a volume sufficient for the experimenter to record the number of response cycles at a rate of at least one response per second. (Most subjects chose to articulate at a rate of about 3 responses per second.) Subjects were then allowed to practise controlling the whale while performing the verbal side task until they re-established criterion performance.

It should be noted that verbal side tasks similar to this one are popularly employed to interfere with the operation of the articulatory loop (e.g., Murray, 1968; Baddeley, Thomas and Buchanan, 1975; or Broadbent and Broadbent, 1981). It is not the task but the conditions of employment which determine the processes involved in its accomplishment. In this experiment, subjects were introduced to the side task in pregame training and most had over three minutes of continuous articulatory suppression by the time the game commenced. Subjects continuous employment of articulation throughout the two and a half minute trial also reduced of intermediate processing demands.

In contrast, Baddeley's (et al., 1975) experiment required subjects to articulate for only approximately 8 seconds at a time (i.e., during stimulus presentation). Since suppression was only involved for 16 of the 32 trials, the total time spent by

Baddeley's (et al., 1975) subjects was about two minutes. Because of its novelty, articulatory suppression performed in this manner would involve intermediate as well as peripheral mechanisms. However, having subjects practise articulation until they re-established criterion-level control performance and then articulate for 9 additional, two and one half minute trials minimized the involvement of intermediate processing mechanisms. In terms of the model proposed in this thesis, side task performance was relatively automatic (i.e., accomplished without recourse to limited capacity processing mechanisms).

After the control training, subjects completed two sets of 9 trials. Half the subjects started with kayaks and the others with plankton. Half of each group employed articulatory suppression on the even trials and the others articulated during odd trials. Six counter-balanced speed schedules were employed across these groups. Males and females were balanced across each of the three conditions (i.e., priority rotations, articulation alternation and speed schedules). Again, subjects' score sheets were annotated to reflect the priority and verbal side task requirements for each trial. The order of temporal presentation was embedded in the game program and thus unobtrusively varied. A short break was taken between the ninth and tenth trials. After the game, subjects completed the Espoused Strategies Worksheet and Subjective Priorities Ratings, the computer-presented incidental learning questions and the Embedded Figures Test.

This experiment was similar to those presented earlier. The most significant difference was the trial-to-trial speed variance. The temporal range over which speeds were manipulated was 90 msec

(which represented nearly a 25 percent increase in the time between stimulus presentation and response registration). However, 90 msec was also the temporal increment for each kayak present during a particular cycle (e.g., if 3 kayaks were present, the cycle required an additional 270 msec to complete). In these terms, the temporal manipulations were the equivalent of a .5 SD shift in the distribution of cycle times inherent in the game. Such shifts should be sufficient to increase significantly the availability of processing resources, but still be below the threshold of subjects' awareness. This manipulation thus was an attempt to insulate previous findings from alternative explanations involving volitional mediation of resource availability based on subjects' misperception of task demands.

Other changes involved incorporating an unpaced verbal side task and allowing subjects to practise combining its performance with controlling the whale before playing the game. Because there was no designated practice period, data from all 18 trials was analysed. The inclusion of the initial trials is particularly important because they represent conditions under which implicit knowledge could not contribute to task performance.

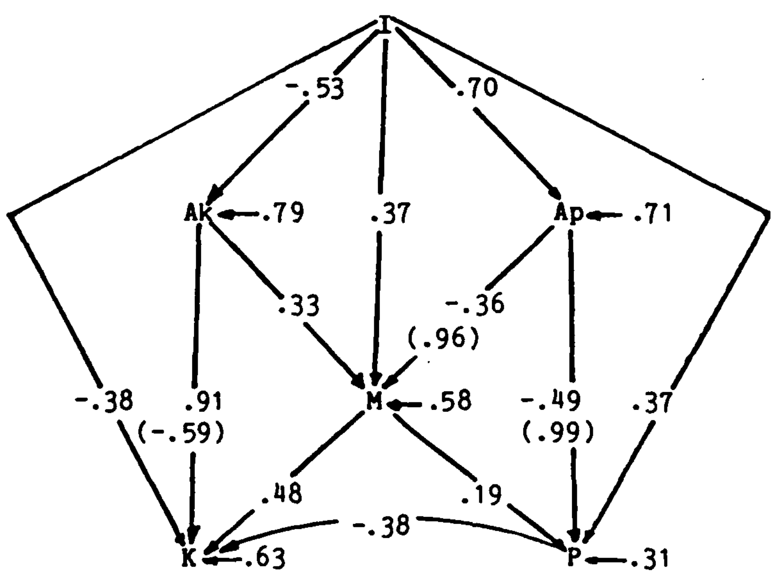
8:3a GLOBAL ANALYSES

Figure 8-1 contains the descriptive statistics and task structure. The general level of performance is better than expected. Achievement of both criteria is slightly above the average for all experiments. The number of directional changes per trial (72.0) implies subjects were effecting changes every 2.15 seconds. This is marginally quicker than the response rate for

DESCRIPTIVE STATISTICS, ZERO-ORDER CORRELATIONS
AND TASK STRUCTURE FOR EXPERIMENT FIVE*

Vari- ables**	I	Ak	Ap	M	P	K	IBE	CEN	LUT	QST
Mean	70.7	4.92	.345	72.0	15.7	9.6	3.36	90.4	72.3	.81
SD	44.9	1.66	.160	19.0	17.0	3.7	2.45	38.0	13.0	1.50
I		-.53	.70	.54	.74	-.60	-.01	-.57	.14	-.51
Ak			-.32	-.03	-.36	.66	-.15	.36	-.70	.74
Ap				.70	.83	-.35	-.08	-.39	.02	-.36
M					.79	-.04	-.18	-.12	-.20	-.19
P						-.41	-.11	-.45	.04	-.37
K							-.19	.63	-.53	.35
IBE								.09	.11	-.14
Cen									-.27	.04
LUT										-.07

TASK STRUCTURE



* N= 432 (24 subjects X 18 trials)

**Variables: I= Intentions (less than three spaces); Ak= Kayak Action System (centre, not lined-up, one quadrant); Ap= Plankton Action System (one space percentage); M= Motor Output System (changes of direction); P= Plankton eaten; K= Kayaks destroyed; IBE= Icebergs eaten; LUT= Line-up time; QST= Commitment to one quadrant strategy.

Figure 8-1

either of the previous experiments. This is surprising; practice exerted a positive influence on the number of directional changes but was nearly one third less than in the two previous experiments. Additionally, the trial-to-trial temporal uncertainty and increased rate of overt articulation were expected to interfere with motor output.

It was noted earlier, the strength of relations between the various measures increased with the level of performance. The strengthened correlations in Figure 8-1 are consistent with this observation. The correlations between plankton performance measures and the criterion ($.74<r<.83$) are very strong. Likewise, the kayak criterion is closely related to both intention ($r=-.60$) and the kayak action system ($r=.66$). The differential importance of the action system's constituents is again clearly reflected; staying in the central region is the most important. The number of icebergs eaten has only a very weak effect on the criteria.

The task structure explains variance in both criteria well but contains two unique features: the curvilinear relation between the kayak action system and the kayak criterion (Figure 8-2b) and the unpredicted negative effect of eating plankton on crashing kayaks. The curvilinearities showing the influence of the plankton action system on the motor control system and the plankton criterion (Figure 8-2a and c) are similar to those encountered and discussed previously. The other linear relations also approximate earlier models. It is the anomalies which require explanation.

The curvilinear relation between the kayak action system and criterion suggests the benefits of following appropriate rules increased most as the value of the action system measure increased

DEPICTION OF CURVES INDICATED
IN EXPERIMENT FIVE TASK STRUCTURE

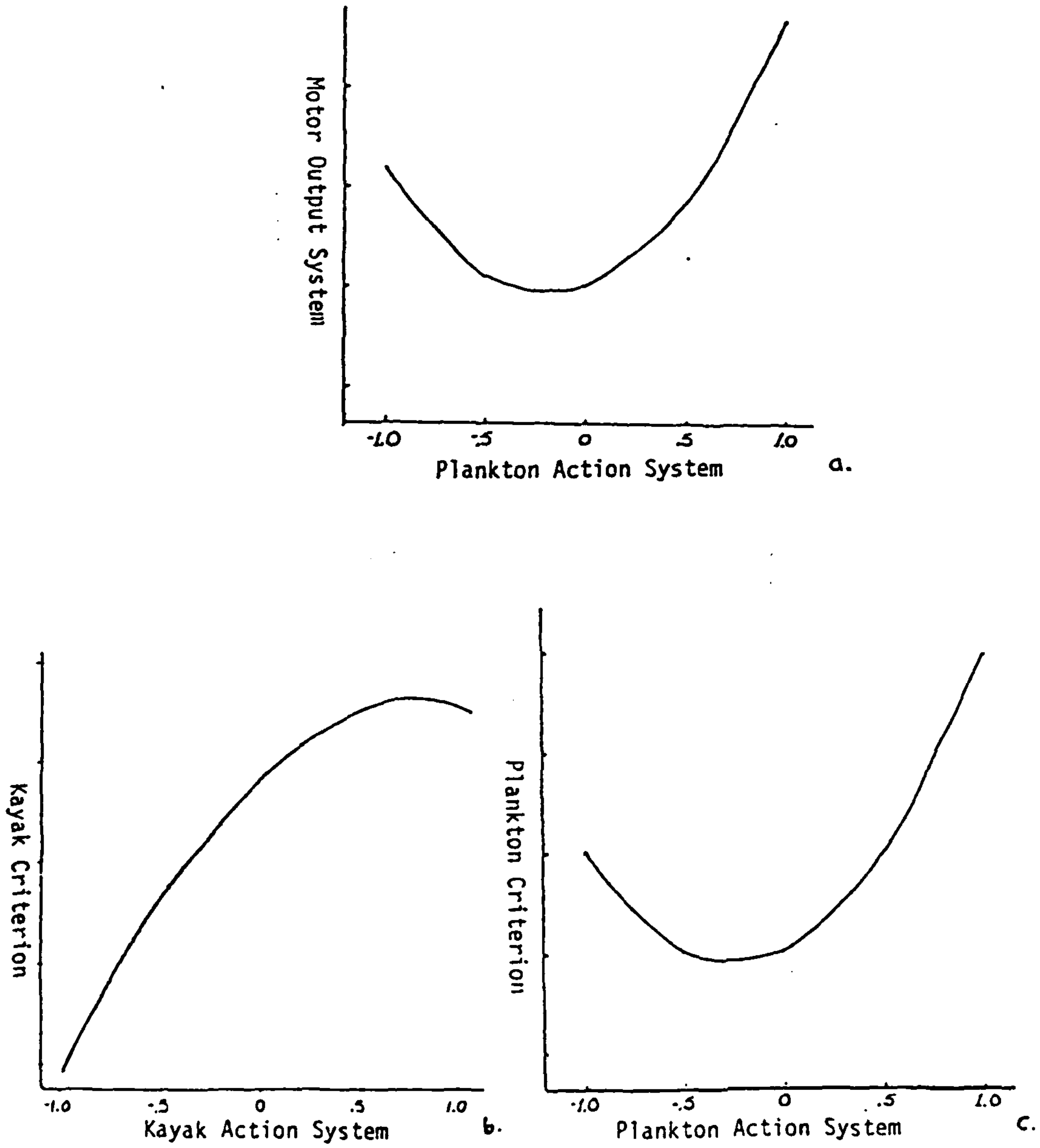


Figure 8-2

from low to moderate levels. Absolute adherence to the rules (e.g., staying in the centre or one quadrant for the entire game) were counter-productive. In a sense, it is surprising this relationship had not emerged from the previous experiments. It is possible the combination of capable subjects and data from early trials contributed to its appearance here. Subjects may have developed strategies by testing their limiting conditions (i.e., discovering how far a strategy could be productively employed by attempting to over-employ it). (Nearly a third of these subjects were graduate psychology students.)

The unpredicted effect of plankton-eaten on kayaks-crashed challenges the adequacy of this model of the task structure. The unexpectedly strong effect implies that, even after indicants of intention, the kayak action system and the motor output are taken into account, achievement of the plankton criterion suppresses performance of the kayak task. A possible explanation involves the differential game speeds and their influence on the performance of the two tasks.

Although subjects were unaware of the speed manipulation, performance on the plankton task benefitted from the slower pace (mean tonnes for the three conditions were 13.3, 15.9 and 17.9 for the fast, medium and slow speeds respectively). Subjects response to such inexplicable success may have been to focus more narrowly on the plankton task to the detriment of the kayak task. This might be similar to the phenomenon of "target fixation" which occurs when a pilot inadvertently sacrifices aircraft control to maintain ideal conditions for weapons delivery. Such an explanation is purely speculative, however. The measurements taken

do not support further elaboration.

The implications of the emergence of this unpredicted path are important. The structure which was adequate for the first four experiments and is not sufficient for these data. Although the depicted model provides an explanation for 90 percent of the variance in the plankton task and 60 percent of the variance in the kayak task, the underlying structure is different. Although a plausible post hoc explanation is available, it neither excuses nor compensates for the model's failure. Other factors are involved; subsequent analyses and interpretation will be undertaken with caution.

In contrast to the anomalies in the analysis of the performance data, the results from the Espoused Strategies Worksheet are quite similar to those from Experiment Three. An extra rule was included for each of the tasks. For the kayak task, this rule corresponded to the one quadrant strategy (the least important constituent of the kayak action system). This rule received subjects' strongest explicit endorsement. The next most favoured rule was the objectively-irrelevant "don't eat the icebergs." Subjects again espoused turning away from the kayaks in direct contradiction of their successful behaviours. The most effective strategy (staying in the central area) received equally positive and negative endorsements which resulted in a perfectly neutral subjective rating (i.e., .00).

Once again the plankton task provides a sharp contrast. The correspondence between subjects' performance and espoused strategies are very strong. Subjects correctly identified the two most important rules, correctly rated the next two in importance

COMPARISON BETWEEN ACTUAL AND ESPOUSED
RULES FOR ACCOMPLISHING TWO TASKS
(EXPERIMENT FIVE)

KAYAK TASK				PLANKTON TASK			
	Utilities		Abslt		Utilities		Abslt
Rules	Obj.	Esp.	Diff.	Rules	Obj.	Esp.	Diff.
Stay in the central area.	.55	.00	.55	Always turn twd the pkt.	.78	.90	.12
Don't turn away from the kyks.	.45	-.42	.87	Stay near the plankton.	.76	.92	.16
Stay near one iceberg clstr.	.35	.71	.36	Don't stay in the centre.	.35	.25	.10
Ignore the plankton.	.34	.50	.16	Ignore the kayaks.	.34	.54	.20
Don't eat icebergs	.15	.58	.43	Don't eat icebergs	.02	.13	.11
Total discrepancy			2.37	Total discrepancy			.69

Table 8-1

AVERAGE RELATIVE SUBJECTIVE
RATINGS OF PRIORITIES
(n = 24)

DIFFICULTY

```
     P                                          K     E
Least 3----------------------2----------------------1 Most
     2.92                                      1.67  1.42
```

COMPLEXITY

```
       P                                    K         E
Least 3----------------------2----------------------1 Most
       2.83                                1.79      1.38
```

UNCERTAINTY

```
                P           K           E
Least 3----------------------2----------------------1 Most
               2.46        2.00        1.54
```

Priorities
P = Plankton E = Equal K = Kayak

Figure 8-3

and recognized the relative insignificance of "eating" icebergs. The generally close correspondence of subjects' responses to those elicited previously suggests both the phenomenological constancy of the game and the reliability of the instrument. (Objective utilities were again taken from average correlations across all five experiments and are thus identical to those employed previously.)

The average relative subjective ratings of the three priority conditions are also nearly identical to Experiment Three. According to most subjects, the equal priority task was the most difficult, complex and uncertain. Several subjects rated the kayak task the highest of all conditions on each of the scales. For difficulty, 11 of the 24 subjects rated kayak priority trials higher than equal priority trials but, for the complexity and uncertainty dimensions, this number decreased to 7 then 4 subjects respectively. Again, the majority of subjects rated the kayak priority trials above plankton priority trials on all three dimensions. Consistent with the design distinction between the two tasks, however, plankton was rated as being more uncertain than complex and kayaks as being more complex than uncertain.

Analysis of the raw data yields several interesting findings. Performance was slightly better than would be expected from the reduced practice, increased number of verbal responses involved in the side task or increased temporal uncertainty. The anomalous influence of plankton eaten on kayak crashing might reflect "target fixation" but still implies the partial inadequacy of the proposed task structure for these data. In contrast, the Espoused Strategies Worksheet responses were very consistent with those of

Experiment Three. Subjects' explicit verbal strategies for performing the plankton task were remarkably consistent with their performance. For the kayak task, however, large discrepancies between the espoused and actual rules again emerged. Subjective ratings of the difficulty, complexity and uncertainty of the three priority conditions were nearly identical to previous ratings.

8:3b BETWEEN-SUBJECTS VARIANCE

In general, the individual difference measures indicate subjects were similar to those employed in Experiments Three and Four. Scores were generally high and standard deviations relatively low. The low correlations between these individual difference measures bode well for subsequent regression analyses.

These performance data support the impressions gleaned from the raw data. Subjects were performing slightly better than the side task, temporal uncertainty and reduced practice predict. The relatively high scores for both action systems and the number of directional changes fully support elevated performance on the criteria. Standard deviations for all measures are comparable to earlier experiments.

The correlation matrix also resembles its predecessors in many respects (e.g., being quicker and brighter is positively related to high scores on all measures). Two of the individual difference measures, however, differ from previous findings. The correlations between the Embedded Figures Test and performance measures are considerably diminished. In contrast, the validity of espoused strategies shows enhanced explanatory utility. Both features deserve comment.

A re-examination of the data on a subject-by-subject basis

BETWEEN-SUBJECTS ANALYSES: DESCRIPTIVE STATISTICS, ZERO-ORDER CORRELATIONS AND STANDARDIZED REGRESSION EQUATIONS
EXPERIMENT FIVE
(n=24)

Vari-	Individual Differences				Hierarchic Measures				Criteria		
					I	Ak	Ap	M	K	2K+P	P
ables	RT	EF	IL	ES	LT3P	CLQK	PACTP	MVST	KDK	PTSB	PEP
Mean	434	12.0	10.7	6.3	119.8	6.66	.465	72.0	12.4	32.5	31.9
SD	48	3.3	1.3	1.4	10.9	1.20	.106	13.3	2.1	9.3	14.6
Correlations:											
RT		-.05	-.23	-.06	-.47	-.36	-.53	-.60	-.66	-.58	-.72
EF			.11	.09	.23	.14	.08	.31	.02	.23	.16
IL				.33	-.03	.53	.54	.55	.42	.57	.53
ES					.18	.35	.48	.46	.50	.60	.47

Standardized Regression Equations

I=-.51RT - .23IL + .23ES
t(20)-2.62* -1.11 1.13
R^2=.29 F(3,20)=2.70 n.s.

Ak=-.34RT + .43IL +2.93ES(-2.77E^2)
t(19) -2.03 2.46* 2.45* -2.31*
R^2=.51 F(4,19)= 4.97**

Ap=-.67RT + .32IL + .35ES
t(20)-2.90** 2.02 2.29*
R^2=.57 F(3,20)= 8.89**

M=-.50RT + .33IL + .32ES
t(20)-3.56** 2.34* 2.21*
R^2=.63 F(3,20)=11.27**

K=-.60RT + .14IL + .42ES
t(20)-4.50** 1.01 3.04**
R^2=.66 F(3,20)=13.20**

P=-.63RT + .27IL + .33ES
t(20)-5.53** 2.23* 2.83*
R^2=.75 F(3,20)=20.17**

PTS=-.48RT + .30IL + .47ES
t(20)-3.94** 2.37* 3.76**
R^2=.72 F(3,20)=17.83**

* p<.05 ** p<.01

Variables: RT= Four-choice reaction time; IL= Incidental learning; ES= Correspondence of Espoused Strategies; E^2= Non-linear aspects of ES; I= Intentions (less than three spaces); Ak= Kayak Action System (centre, not lined-up, one quadrant); Ap= Plankton Action System (one space percentage); M= Motor Output System (changes of direction); P= Plankton eaten; K= Kayaks destroyed.

Figure 8-4

produced a possible explanation for the mysterious disappearance of the predictive utility of the embedded figures score. Including graduate psychology students in the sample introduced two opposite effects. Some of these "pseudo-subjects" had, in fact, administered and scored embedded figures tests in their own research. For them, the test was trivial; they easily scored near the maximum. Other students, however, recognized embedded figures as "intelligence tests" and responded somewhat negatively. Their performance on the embedded figures was inappropriately poor.

These two cases accounted for most of the extreme values in the distribution of embedded figures scores. Because neither of these factors (i.e., test familiarity nor reacting negatively to intelligence tests) was related to the dimension assumed to underlie the instrument (i.e., field dependence), the instrument's predictive utility decreased. As explained earlier, (after examining the data for evidence of interactions) this "weak" measure was omitted from subsequent regression analyses.

The surprisingly strong correlations of the espoused strategies with performance measures also merit comment. The validity of subjects' espoused strategies for the separate tasks were considered independently but the simple sum of validity scores provided the best overall correlation with performance and criteria measures. The correlations with criteria ($.47<r<.60$) are much stronger than those observed in Experiment Three and contrary to the significantly negative correlation between explicit knowledge and task performance reported by Berry and Broadbent (1984). The Espoused Strategies Worksheet may be particularly well-suited for identifying relevant aspects of subjects' explicit verbal

knowledge.

The standardized regression equations tell a relatively simple story. The three individual difference measures (reaction time, incidental learning and validity of espoused strategies) combined to provide significant explanations for all measures except intention (which is again consistent with the conceptual definition of this variable). Without exception, subjects who were quicker, brighter, and espoused more appropriate (i.e., fewer invalid) strategies were more successful than those who were slower, less bright and espoused inappropriate strategies. The absence of significant interactions suggests these factors exerted relatively independent influences.

The single significant curvilinear relation involved the kayak action system and is plotted in Figure 8-5. This function shows that subjects whose explicit strategies were at or above the mean validity tended to follow appropriate rules during kayak priority trials. For subjects who espoused generally inappropriate strategies, rule-consistent performance decreased sharply as espoused strategies were progressively more inappropriate. Having perfect explicit strategies was less important than simply having adequate ones (i.e., ones of average validity). It was not the absence of precisely accurate knowledge which limited performance; rather, it was the presence of integrated and consistent but inaccurate strategies which was the greatest impediment.

Although generally consistent with previous findings, the between-subjects analyses revealed several paradoxes. Employing the Embedded Figures Test with a sample containing a large portion of non-naive graduate psychology students was inappropriate.

DEPICTION OF CURVE INDICATED
BY BETWEEN-SUBJECTS ANALYSIS OF
EXPERIMENT FIVE DATA

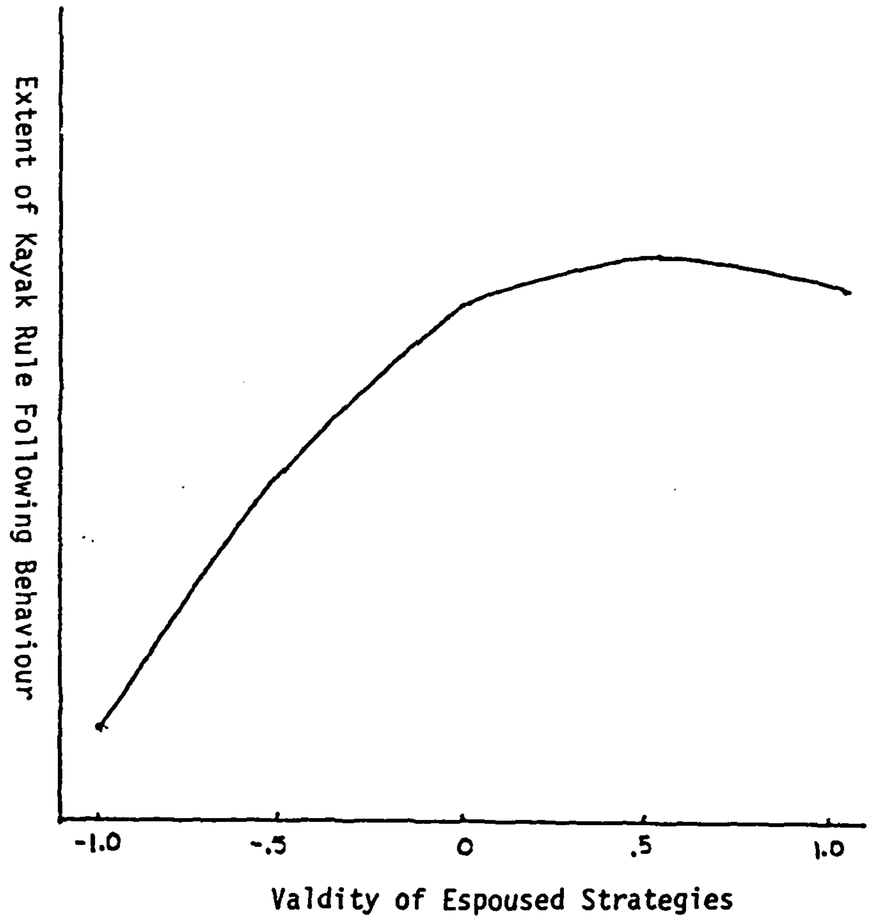


Figure 8-5

Fortunately, the validity of espoused strategies showed unexpectedly strong correlations with the performance measures. The relationship between the validity of espoused strategies and rule-consistent performance during the kayak priority trials is curvilinear. The strongest positive effect of validity on game activities appeared among those subjects who espoused generally inappropriate strategies.

8:3c WITHIN-SUBJECTS VARIANCE

Differential conditions exerted strong influences and thus provide explanations for large portions of the within-subjects variance for most of the measures. As observed in earlier studies, these influences did not, however, provide adequate explanations for the "line-up time" or "icebergs eaten" measures. Additionally, the kayak action system indicant was not significantly explained by conditional influences. The loss of information the analysis of this variable might have provided is unfortunate. For the remaining dependent measures, priority, practice, suppression and speed show interesting patterns of influence. These will be discussed sequentially.

Priority (PRI) again exerted the pre-eminent influence on all measures. In addition to strong main effects, there were also several non-linear effects and significant interactions with practice were ubiquitous. The raw data reflected a slight bias toward the kayak task during equal priority trials (+.07 SD), but the intention measure does not show a significant curvilinear component (P^2). Similarly, the plankton action system measure does not show any bias. However, all three measures occurring lower in the structure (i.e., the number of directional changes and

REGRESSION EQUATIONS SHOWING WITHIN-SUBJECTS INFLUENCES ON SELECTED PERFORMANCE AND CRITERIA MEASURES FOR EXPERIMENT FIVE

Intention = 8.64 PRI − .66 RUN + .59 RXP + 30.95
t(360) = 14.15** −1.95 3.79**
R^2 = .82 F (54,360) = 30.37**

Pkt Act Sm = 4.56 PRI − 1.21 RUN + 1.15 RXP + 37.08
t(360) = 4.79** 2.24* 4.67**
R^2 = .58 F (54,360) = 6.56**

Centre Reg = 8.37 PRI + 2.86 RUN − 1.05 RXP + 44.91
t(342) = 2.43* 4.82** −3.71**
R^2 = .47 F (72,342) = 4.21**

Quad Stgy = 2.90 PRI − 18.49 P^2 + 73.49
t(342) = 3.37** −5.33**
R^2 = .35 F (36,378) = 5.65**

Drct Chngs = −6.73PRI + 2.69P^2 + .99RUN − 1.55ASP + 1.17SPD + .78RXP + 40.39
t(306) = −2.14* 3.62** 1.82 2.19* 5.51** 3.15**
R^2 = .60 F(108,306) = 4.25**

Pkt Eaten = −10.52PRI + 3.05P^2 − 1.92RUN − .25SPD + 1.70RXP + .23P^2S + 49.92
t(306) = −5.28** 6.39** −5.61** 1.08 10.29** 5.57**
R^2 = .84 F(108,306) = 14.88**

Kyk Crshs = 1.72 PRI − 2.08 P^2 + 2.20 RUN − .62 RXP + 52.90
t(342) = .58 2.95** 4.27** −2.64*
R^2 = .59 F (72,342) = 6.84**

* $p < .05$ ** $p < .01$

Independent Variables:

PRI - Priority instructions (1- kayaks; 2- equal; 3- plankton)
P^2 - Curvilinear effects of priority instructions (PRI^2)
RUN - Amount of Practice in 3-trial increments (4 through 9)
RXP - Interaction between priority and practice (RUN*PRI)
ASP - Articulatory suppression in fixed sequence (1,0)
SPD - Delay in cycle speed (0- no delay; 2- 45 msec; 4- 90 msec)
P^2S - Interaction between speed and curvilinearity of priority

Figure 8-6

the two criteria) show significant curvilinearity. For the motor output indicant and plankton criterion, increases from medium to high priority resulted in greater proportionate improvements than increases from low to medium priority. Kayak task performance, however, showed the opposite effect. The increase from moderate to high priority for kayaks resulted in less improvement than the increase from low to moderate priority.

Practice (RUN) interacted with priority for every measure except the single quadrant strategy. This suggests improvements with practice were mediated by explicit priority instructions and presumably subjects' conscious intentions. The significant emergence of these interactions (RXP) reflects both the general elevation in the R^2s and the inclusion of the initial game trials in the analyses. Closer inspection of the interactions shows the largest effects occur in the plankton criteria and action system measures.

The general lack of significant interference from unpaced articulatory suppression is consistent with the argument presented earlier. (Articulatory suppression was omitted from the regression equations to which it did not significantly contribute.) The data indicate articulatory suppression's only significant effect was on the motor output system, and this was only significant at the .05 level. The articulatory side task depressed performance by an average of .15 SD (or slightly less than three changes of direction per trial) and did not interact with any other influences. The lack of significant interactions between the game pace and articulatory suppression are particularly noteworthy. In addition to being slight the interference effects of unpaced suppression

(assumed to be localized in the motor output system) were relatively independent of the other influences. (This argues strongly against a motor-interference explanatory alternative.)

In contrast, the effects of speed are strong but focussed on two measures, the number of directional changes and the plankton criterion. Additional time had a strong, linear and positive effect on the number of directional changes. Compared to the fast condition, the increased performance associated with the 90 msec delay (coded as 4) was .47 SD (an average of nearly 9 directional changes). However, the lack of a significant interaction between suppression and game pace suggest the loci of their influences were different.

The effect of speed on the tonnes of plankton eaten is more complex. Extra time interacted strongly with the curvilinear effect of priority. At slower speeds, the tendency of performance to increase more with the shift from medium to high priority is accentuated. Whatever accounts for the extra boost in performance with high priority is strongly time-dependent. The absence of either main or interactive effects on the kayak task provides an interesting contrast. Although practice, intention and their interaction are important to the kayak task, the manner in which these factors influence criterion achievement is less mediated by time-dependent processes.

Graphical analysis will again be employed to illustrate these influences. Rather than simply concentrating on task performance during the respective high priority trials, performance averages for each task under all priority conditions at two levels of practice are shown in Figure 8-7. Again each data point reflects

EFFECTS OF TIME AND PRACTICE
ON STANDARDIZED MEASURES OF
KAYAK CRASHING AND PLANKTON EATING

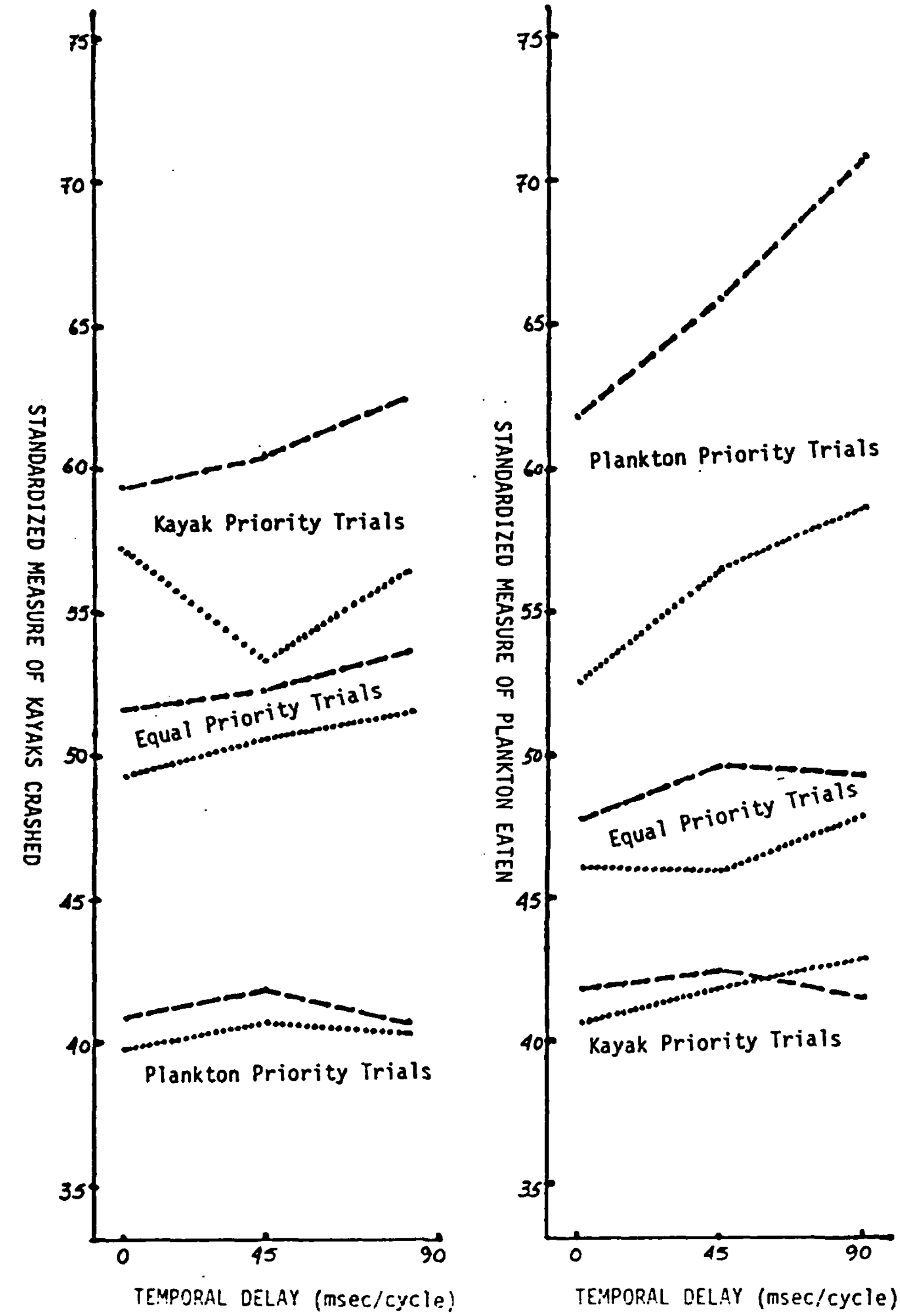


Figure 8-7

the performance of all 24 subjects. Half the subjects in each case were employing articulatory suppression and the order of presentation and level of practice were counterbalanced across subjects. Data from the first 9 trials are connected with dotted lines and the second group of trials by broken lines.

Kayak task performance is plotted on the left. The significant influence of priority instructions is shown by the vertical spread of the three sets of horizontal curves. The effects of practice are reflected by the elevation of performance during the second set of trials (broken lines) within each priority pair. The interaction between practice and priority is shown by the larger effects of practice which occur as priority increases.

Although the graphical representation is consistent with the influences suggested by the regression equations, there is one clearly aberrant curve. Performance on the kayak task during kayak priority trials in the first set of trials is curious. Not only is there a net decrease in performance with increased time, the large dip at the moderate speed is particularly counter-intuitive. The explanation that this dip was simply the result of a few subjects doing very badly is contrary to the evidence. The standard deviation for performance along this curve (6.33) is less than either the standard deviation for the equal priority trials at the same level of practice (7.91) or the kayak priority trials on the subsequent set of trials (7.14).

Since all three speeds were presented an equal number of times, the middle speed was "prototypical" (i.e., most representative) and thus should have shown facilitory effects if any (Posner & Keele, 1968). However, if the use of processing

resources interfered with kayak performance, such a dip might be expected. The orderly improvements in kayak performance with time during the second set of trials or during both sets of trials for the equal priority trials provide interesting contrasts. It appears that attentional resources are only initially noxious (i.e., until augmented by positive influences from the implicit knowledge gained from practice) when mixed with a high level of intention.

The performance plots for the plankton task illustrate the myriad influences shown by the regression equation. The main effect of priority is shown by the vertical displacement of the pairs of curves and the effects of practice by increases within the pairs. The curvilinear influence of priority is shown by the downward displacement of the equal priority curves. The pronounced interaction between practice and priority is shown by the greater influence of practice with increased priority. The main effect of speed is shown by the positive slope of the curves. The most interesting (and complex) effect, however, is the interaction between the curvilinear influence of priority and speed. Extra time enhances the relative advantage of increases from moderate to high priority.

The results of the within-subjects analysis are interesting for several reasons. The failure of the kayak action system to respond to conditional influences may be a further manifestation of the problem which caused the task structure anomaly in the general analysis. Priority was again shown to be the pre-eminent within-subjects influence. The opposite curvilinear effects shown for the two subtasks (i.e., the greater performance increments

associated with shifts from low to moderate priority for the kayak task and from moderate to high priority for the plankton task) replicate previous findings. Inclusion of the initial trials in the analysis probably contributed to the enhanced effects of practice and also the emergence of significant interactions between practice and priority for most variables.

The effects of the manipulation of time and the lack of effects from unpaced articulatory suppression are perhaps the most conceptually significant. The plankton task (particularly the "concentration bonus" occurring at high priority) benefitted greatly from the slower pace. In contrast, time showed only weakly positive effects on the kayak task. Unpaced articulatory suppression showed slight interference with the motor output system but did not affect any of the other dependent measures. These results provide relevant and generally convergent evidence for the proposed information processing model.

8:4 DISCUSSION

Although generally successful, this experiment revealed a weakness in the model of task structure which had provided a consistent and coherent explanation for data from four previous experiments. The falsification of the proposed task structure demonstrates that the model cannot be applied with impunity to all versions of the game and conditions of play. In this sense, it provides an exception which reinforces the propriety of the model's application to previous data. The model can be falsified. Its failure for these data is nonetheless bothersome. It is not obvious whether the inadequacy rests with the structure or simply reflects the inadequacy of one or more of its components.

There is reason to suspect the heart of the problem lies in the indicant of the kayak action system. Intention, action and motor output systems show consistent inter-relations and provide an explanation for the performance of the plankton task very similar to previous ones. The kayak action system measure, however, shows a unique curvilinear influence on the kayak criterion. The kayak action system also uniquely reflects a curvilinear influence of one of the individual difference measures (viz., espoused strategy validity). Additionally, the failure of the kayak action system to respond significantly to within-subjects factors (i.e., priority and practice) suggests different relations may underlie this version of task.

The curvilinear influence of the kayak action system on the criterion may have allowed the plankton eaten variable to provide the unpredicted substantive contribution. Such post hoc explanation, however plausible, remains largely speculative. Whatever the reason, the unpredicted appearance of this path suggests the hierarchic model does not fully account for the performance of the kayak task in this experiment.

This "failure" contrasts with the success in replicating the results from the previous administration of the Espoused Strategies Worksheet. The consistency of both strategy selection and subjective ratings of the priority conditions are noteworthy. The subjective ratings will be discussed first.

Subjects appeared to have relatively little difficulty providing ratings for the three priority conditions. Several descriptive phrases were provided to help subjects "understand" the dimensions along which they were to rate the trial types. However,

many gave the impression of making their ratings with much less effort and greater spontaneity than they showed in working out their explicit strategies. (This is consistent with arguments posed by Osgood (1969) or Zajonc (1980) for the pre-cognitive basis of evaluations.)

The subjective ratings are consistent with those received from subjects during Experiment Three. Apparently the different side tasks, levels of practice and temporal manipulations had little effect on how subjects experienced and consequently reported their reactions to the game. The consistency of the subjective differentiation of the priority conditions is itself a little surprising when one considers that conditions for each trial were virtually identical. The whale control system, iceberg constellation, movement of the plankton and time and place of kayak appearance were all the same. The environment was perpetual; the changes were entirely contained in the verbal instructions (and points display) and consequently subjects' minds.

Subjects' selected explicit strategies were very similar to those chosen in Experiment Three. The close correspondence between the validity of subject's selections and their performance suggests a functional similarity between filling in the worksheet and playing the game. The difference in the relative correspondence between espoused strategies and actual performance for the two tasks is again clear. For the plankton task, there was great consistency between what subjects did and said. Although selected strategies for the kayak task generally matched those chosen in Experiment Three, they again showed little correspondence to actual performance.

An explanation for this dissociation was suggested earlier. The increased number of parameters involved in the more complex kayak task exceeds the capacity of attentional resources. Much of the necessary augmentation for improved performance is provided by the gradual development of internal representations of the task structure based on constant relations inherent in the task itself. This mental model is largely implicit and not available for verbal report.

Consequently, when subjects are required to produce explanations, they work out coherent but independent post hoc accounts. Such confabulation shows consistency because the information available (viz., subjects' impressions and phenomenological experiences) is similar. However, the resultant set of espoused strategies bears little correspondence to the processes actually involved for the kayak task. In contrast, the strategies espoused for the simple plankton task are entirely consistent with performance.

Analysis of the between-subjects variance contained the familiar suggestion that subjects who performed "better" on a range of individual difference measures also performed better during the game. The game tasks did not show specific effects of these relatively independent measures of individual differences. The inappropriate employment of the Embedded Figures Test with a sample containing many non-naive subjects resulted in the loss of predictive utility. This loss, however, was offset by an increase in the predictive utility of the validity of espoused strategies. Evidence was presented to suggest it was not so much the absence of perfect strategic information as the presence of coherent sets of

inappropriate strategies which most impeded performance.

The primary focus of this experiment was, however, the manipulation of conditions affecting within-subjects variance. As presented in the introduction, this experiment sought to address three issues. One was the possibility that previously observed results reflected subjects' volitional mis-allocation of resources based on their inaccurate appraisal of the "difficulty" of the two tasks. Another issue involved the measurement of the direct effects of concurrent peripheral motor activity on the various performance measures. A final issue involved examining the combined effects of general and verbal processing mechanisms in the absence of viable parameter specification being provided by implicit knowledge. Experimental results will be discussed briefly with respect to each issue.

The two 45 msec temporal shifts produced effects similar in size to those caused by previous side task conditions (i.e., paced randomized suppression or the 5-letter memory load). However, unlike the verbal side tasks, this manipulation was not apparent to subjects (i.e., post-game questioning revealed that none were aware of the trial-to-trial temporal variation). Because subjects were unaware of the increased availability of processing resources, intentional mediation was not possible.

The effects of the temporal manipulations are themselves of interest. As the previous experiments have shown, both the central executive and articulatory loop contribute to the performance of the plankton task. In contrast, the kayak task is assumed to benefit (at least initially) from general resources but some evidence has been presented to suggest intermediate verbal activity

might actually interfere with performance of this task. Since time (like the rain) indiscriminately benefits all (temporally-constrained) processing, different effects on the two game tasks might be expected.

Extra time should facilitate performance of the plankton task. Because general processing facilitation would be offset by interference from verbal processing, the net effect of time on the kayak task would be minimal. The results show this pattern. The graphical presentation provides further relevant evidence. The only negative temporal influence on the kayak task occurs at the nexus of low practice and high priority. Such conditions might reasonably be associated with high levels of task relevant self-instruction, evaluative remarks or attempts to solve the performance problem verbally.

The direct effects of motor activity were represented by the influence of unpaced articulatory suppression. This task involved only one set of contents and subjects were allowed to practise the task in conjunction with control performance before beginning the game. Since subjects articulated continuously throughout nine trials of about two and one half minutes each, they received a great deal of practice. Under these conditions, it was assumed articulation would be relatively automated and thus place few demands on intermediate processing mechanisms.

There is reason to believe that even the oft-cited obligatory intrusion of verbal material on the operation of the articulatory loop (Baddeley, 1983; Hitch, 1980) might not obtain under these conditions. To the extent the material subjects articulated was reduced from meaningful words to a simple fixed sequence of

phonemes, it became less verbal and therefore less likely to interfere with the intermediate portions of the articulatory loop. In this respect the side task became very similar to having subjects click with their tongues or tap their foot.

The results suggest several things about unpaced articulatory suppression: it had only highly-focussed and non-interactive effects; the only significant effect was on the indicant of the motor output system; and the size of this effect was smaller than any of the side tasks previously employed. The effect of unpaced suppression on both criteria was extremely small (i.e., less than one fifth the non-significant effect of speed on the kayak task and less than one tenth speed's significant effect on the plankton task).

While it is not possible to prove the null hypothesis (viz., that motor interference has no effects), these results suggest explanations which rely heavily on differential motor interference are deficient. Additionally, although unpaced articulation involved a response rate about four times greater than the paced articulation employed in the previous experiment, its effects on the plankton criterion was only one sixth as great.

The final issue involved the contribution of processing mechanisms (resources) in conditions where implicit knowledge could not make viable contributions to criteria achievement. By employing side tasks from the onset, data from these conditions could be examined. These initial trials increased the influence of practice on both tasks. Significant interactions between priority and practice emerged for nearly every measure. However, practice did not interact with the manipulations of game speed (i.e., the

availability of processing resources). This suggests the influences of active intermediate cognitive processes (i.e., verbal or general) are relatively independent of the contributions made by implicit knowledge. This also indicates the influences observed in previous experiments were not critically dependent on the availability of alternative sources of parameter specification.

These results are consistent with those from previous experiments and the theoretical model proposed in this thesis. The differential correspondence between espoused and de facto strategies for the two tasks was clearly replicated. Strong evidence against intentionally-mediated or motor-interference alternative explanations for earlier data was also presented. The effects of the time manipulations were focussed. By far the greatest benefactor of additional time (the "universal" resource) was the exponential increase in plankton-eaten with high priority. In contrast, under conditions of high priority and low practice, extra time was actually associated with lower levels of criterion achievement for the kayak task.

A FUNCTIONAL EXAMINATION OF INTERMEDIATE COGNITIVE PROCESSES

CHAPTER NINE

SUMMARY AND SYNTHESIS

9:1 INTRODUCTION

A great deal of material was presented in the last five chapters. The lack of a specifically-relevant literature precluded a simple, focussed and sequential progression of experiments. In comparison to traditional approaches, the ones in this thesis might appear as empirical groping and hoping. Although somewhat unconventional, the "contextualist" approach allowed the incremental development of a novel empirical tool (viz., an arcade-type computer game). This approach also guided the derivation of useful measures and analytic procedures for garnering conceptually-relevant evidence from subjects' performance.

The results of the experiments, particularly the counter-intuitive ones, are pertinent to several current theoretical issues in information processing. Combining the data from the five experiments allows further analysis at a more global level. The consistencies as well as the exceptions that comprise the molar pattern of results are of interest.

This chapter contains a review and synthesis of the five experiments. First the experiments themselves will be compared along several procedural and methodological dimensions. Although the experiments involve minor differences, the substantive similarity provided by the game structure enables meaningful combination of results. Findings from each type of analysis (i.e., the raw-data, the between-subjects variance and within-subjects variance) will be combined across the experiments. The results of

these meta-analyses provide additional evidence relevant to the model. This information will be combined and integrated with the model introduced in Chapter One.

9:2 METHODS

Before proceeding with the quantitative combinations of data, it is useful to review the different versions of the game and the experimental contexts in which they were employed. Each of the experiments differed from the others in several ways. The first two were rather elaborate pilot studies. The game remained relatively constant for the three subsequent experiments, but the number and nature of side tasks varied. Although the myriad of small changes render singular and direct comparisons problematic, they justify greater confidence in effects which appear with consistency across experiments. Relationships based on evidence gleaned from different experiments and receiving convergent support from relatively independent analyses are unlikely to critically depend on a narrow range of conditions.

It is, however, important to review the range of conditions involved. To the extent other situations lie outside conditions involved in the five experiments, the structures and underlying relationships observed might not prevail. Figure 9-1 contains comparative descriptions of the five experiments. A brief discussion of each is warranted.

Slightly different subject samples were used in the five experiments. The decision to restrict participation to the "student or equivalent" group for the last three experiments was based on the observation that performance tended to converge with

COMPARISON OF GAME PARAMETERS AND EXPERIMENTAL CONDITIONS FOR EXPERIMENTS ONE TO FIVE

	EXPERIMENT ONE	EXPERIMENT TWO	EXPERIMENT THREE	EXPERIMENT FOUR	EXPERIMENT FIVE
Number of Subjects	10 Female 10 Male	20 Female	10 Male 10 Female (student or equiv.)	12 Male 12 Female (student or equiv.)	12 Male 12 Female (student or equiv.)
Total time Experiment	2 hours	2 hours	3 hours	2 hours	2 hours
Pre-game Activities	4-Ch RT Task (1*100 cycles)	4-Ch RT Task (2*75 cycles) Adaptive Whale Trng	4-Ch RT Task (2*75 cycles) Adaptive Whale Trng	4-Ch RT Task (2*75 cycles) Adaptive Whale Trng	4-Ch RT Task (2*75 cycles) Adaptive Whale Trng Adaptive Whale Trng w/side task
Number of Trials	17 (5 single task)	15	27 (9 practice)	24 (6 practice)	18
Time/Trial	3 min 12 sec	2 min 52 sec	2 min 42 sec	2 min 25 sec	2:26-2:34-2:45
Time/Cycle	764 msec	796 msec	747 msec	669 msec	671--711--760
Min lag tm	360 msec	200 msec	160 msec	160 msec	160 msec
Fixed base	310 msec	520 msec	510 msec	400 msec	400--440--490
Incrmt/kyk	80 msec	70 msec	70 msec	90 msec	90 msec
Summary of Game Chngs and Side Tasks	iceberg "hint" 251 cycles/trial 25 kayaks/trial 3 iceberg cnstlns no points lost	hint deleted 217 cycles/trial 20 kayaks/trial 1 constellation kayaks win/lose 4 pkt start loc.	memory load s.t. 0 letter 3 letter 5 letter	diff I-bgs prctc altn pkt paths artic sprsn s.t. control fixed order randomized	cycle time vrnc unpaced artic sprsn

Figure 9-1

increased practice or subject ability. The last three experiments also incorporated gender-balanced designs. Males' greater arcade experience generally enabled them to perform better on the Save the Whale game. Counter-balancing gender helped equalize the levels of performance between experimental groups and also provided a relatively wide range of performance.

Total time for most experiments was two hours. Subjects could complete about 18 trials per hour; additional time was devoted to pregame activities and post-game questionnaires and ratings. The pre-game activities were important for several reasons. The 4-choice reaction task familiarized subjects with the spatial orientation of the controls and adaptive whale training taught them the temporal characteristics. Both activities were relatively simple and particularly useful to subjects who had not previously played computer games.

The next section of Figure 9-1 contains comparisons of several temporal measures. Total trial time ranged from over three minutes to about two and one half minutes. The average cycle time (i.e., game pace) was about 750 msec for the first three experiments then decreased to 670 msec for Experiment Four. Pace was directly manipulated in Experiment Five.

The final section of Figure 9-1 includes synopses of the most important changes or side tasks involved in each experiment. The initial experiment was a pilot; many of its features were abandoned in subsequent versions of the game (e.g., single-task trials, more cycles, multiple presentation schedules and iceberg constellations and the inadvertently misleading hint about not eating icebergs).

With unnecessary variation trimmed away, the shortened

version of the game employed in Experiment Two proved a more useful tool. "Allowing" subjects to lose points each time their whale was harpooned helped make the game more interesting. Experiment Three contained a verbal side task which involved memory loads of 0, 3 or 5-letter strings introduced after 30 minutes of game practice. The version of the game employed in practice was the same as the one used in subsequent experimental trials.

Experiment Four also involved a verbal side task but the six initial practice trials used a different constellation of icebergs and kayak generation schedule. The uncertainty of the plankton's path was increased by introducing alternate initial directions of travel. Experiment Four employed two qualitatively distinct side tasks (i.e., fixed-sequence and randomized articulatory suppression). In both instances, responses were "paced" by a mechanical metronome at a rate of one response every 1.5 seconds. In Experiment Five, the game pace was directly manipulated and unpaced articulatory suppression was performed on alternate trials throughout the game.

In addition to recognizing the range over which the experiments varied, it is also important to be cognizant of the ways in which the experiments were similar. In Chapter One it was argued ecological validity involves three issues: meaningful contexts, substantive tasks and adequate measurement and analysis. Each of the experiments incorporated features to address these issues.

Employing a game format with a plausible cover story, allowing subjects freedom in deciding how to perform the tasks and ensuring they monitored their own performance helped establish a

meaningful context for performance. In fact, subjects' affective responses often reflected intense involvement. The tasks incorporated in the game posed viable performance problems. Although subjects could perform above the level of chance (basically zero for both tasks) and showed improvement with practice, few approached perfection. The tasks involved different intermediate processes but neither ceiling nor floor effects were encountered for either task. Many objective measures of performance were taken. Subsequent analyses of these data revealed a relatively robust and enduring task structure. Three consolidated data analyses will now be considered separately.

9:3 GENERAL ANALYSES OF RAW DATA

A summary of the descriptive statistics, zero-order correlations and task structure are contained in Figure 9-2. Values shown were derived by simply averaging across the five experiments. The standard deviations are also averages from the five experiments and thus do not reflect the variance between experiments.

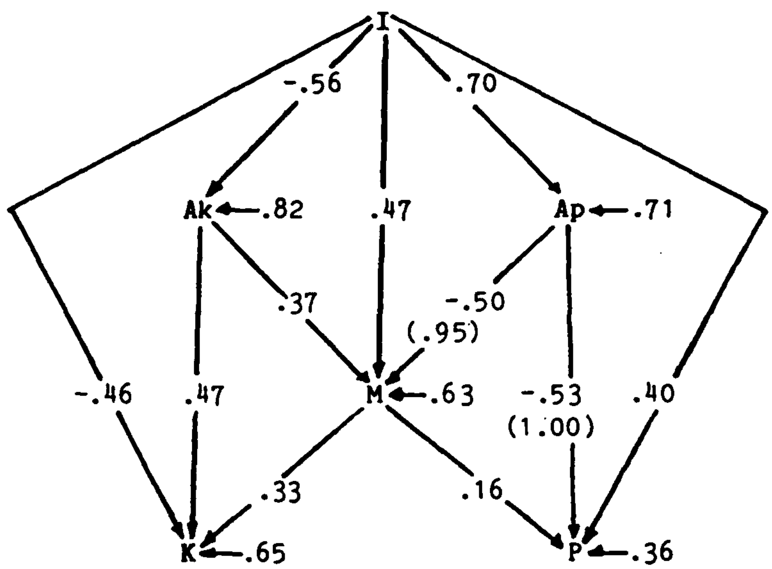
These averages provide general information concerning the level of performance. Subjects spent about one third of the time during the game near the plankton. During the time subjects were within three spaces of the plankton, they were one space away about one third of the time. This shows a strong orientation toward the plankton; only 4 of the 24 spaces in this proximal area are adjacent to the plankton (i.e., a value of .167 would be expected if the whale's distance from the plankton were random within the three space area).

The average number of directional changes (67.3) divided by

SUMMARY OF
DESCRIPTIVE STATISTICS, ZERO-ORDER CORRELATIONS
AND TASK STRUCTURE
AVERAGE VALUES - EXPERIMENTS ONE THROUGH FIVE*

Vari-ables**	I	Ak	Ap	M	P	K	IBE	CEN	LUT	QST
Means	72.0	4.99	.325	67.3	13.3	9.4	3.10	93.9	69.7	.89
SD	46.1	1.89	.141	17.6	13.8	3.7	2.28	37.9	21.5	1.47
I		-.50	.67	.54	.76	-.48	-.01	-.48	.15	-.52
Ak			-.35	-.01	-.38	.68	-.05	.62	-.64	.64
Ap				.58	.78	-.28	-.03	-.35	-.00	-.39
M					.73	.08	-.05	-.05	-.15	-.16
P						-.34	-.02	-.35	.06	-.40
K							-.15	.55	-.45	.35

TASK STRUCTURE



* unit wtd avg from experiments 1-5 (108 subjects, 2,188 trials)

**Variables: I= Intentions (less than three spaces); Ak= Kayak Action System (centre, not lined-up, one quadrant); Ap= Plankton Action System (one space percentage); M= Motor Output System (changes of direction); P= Plankton eaten; K= Kayaks destroyed; IBE= Icebergs eaten; LUT= Line-up time; QST= Commitment to one quadrant strategy.

Figure 9-2

the average game duration (2 minutes 45 seconds) suggests subjects changed their whales' directions of travel once every 2.45 seconds. Other data show subjects consumed just over 3 of the 18 icebergs present at the beginning of each trial. It was not too unusual for a subject to completely "wipe out" a cluster containing between 3 and 6 icebergs.

Although the multiplicity of measures are interesting and provide rich descriptions of different aspects of task performance, the criteria are arguably the most important. The occurrence of these events were the goals to which subjects aspired. Each time the location into which the whale was about to move was occupied by the flashing plankton symbol, the computer beeped, subjects scored points and were credited with eating one tonne of plankton. Subjects' performance is about 15 percent of optimal and the standard deviation represents 15 percent of the range of possible scores. Twenty kayaks were launched and it was possible to force each of them to crash. Comparing the raw data to this standard suggests average performance was 47 percent of optimal and the standard deviation was 11 percent of the possible range.

The next section of Figure 9-2 contains the average zero-order correlations for the five experiments. Correlations are relatively strong for measures relating to the performance of the plankton task (i.e., $.73<r<.78$ between intention, action and motor output and the plankton criterion). Intention shows a slightly weaker correlation with the kayak criteria ($r=-.48$) but the relation between the kayak action system and criterion ($r=.68$) is stronger. Bearing in mind these average correlations reflect performance from nearly 2,200 trials by over 100 different

subjects, the relations suggested are not only significant; they are substantive.

The correlations involving the three constituents of the kayak action system (Ak) (viz., CEN, -LUT and QST) are interesting for several reasons. The differential strength of the relationships between rule-consistent activities and achievement of the kayak criteria is shown on the bottom line of the matrix. Staying in the central region explained 30 percent of the criterion variance; not staying "lined-up" with the kayaks explained 20 percent; and the one quadrant strategy was related to about 12 percent of the criterion variance. The weak relation with icebergs eaten ($r=.15$) accounts for only 2 percent of the variance in the kayak criterion.

These correlations were used as the objective base line for comparing subjects' espoused strategies to their actual performance in Experiments Three and Five. Because the data for the two (shown in Tables 6-1 and 8-1) are so similar they have not been reproduced here. The average endorsements for kayak rules are: stay in one quadrant (.71), don't eat icebergs (.67), stay in the central region (.05) and turn away from (or line-up with) the kayaks (.40). The relationships between the actual occurrence of rule-congruent activities and subjects' general intentions (the last four columns of the top row of the matrix) and criterion achievement (the bottom row of the matrix) are not consistent.

The iceberg rule is strongly endorsed but related to neither intention nor criterion achievement (i.e., a popular myth). Although the centre rule is not explicitly endorsed it is strongly related to the intention indicant ($r=-.48$) and even more strongly

related to criterion achievement (r=.55). This rule represents an undiscovered (or at least unespoused) truth. The line-up time rule is perhaps the most unusual. This rule is explicitly rejected by subjects (i.e., they endorse turning away from kayaks as an appropriate strategy). Thus the line-up rule is not merely a myth but a fallacy. Although line-up time is correlated with criterion achievement (r=-.45), its relation to intention is very slight (r=.15). The one quadrant rule, although not the best strategy (r=.35 with criterion achievement), was strongly endorsed (.71). It shows a close relationship with the intention indicant (r=-.52) but, as just noted, a relatively weak correlation with kayak crashing. It is a belief of exaggerated validity. It is intuitively obvious how the application of such a miasma of explicit "knowledge" might have less than salutary effects on performance.

In contrast, the analysis of the espoused strategies for the plankton task follow a simple, rational pattern. Activities closely related to criterion achievement are strongly endorsed, those moderately related receive moderate endorsement and the single irrelevant activity (i.e., iceberg eating) is identified as such (receives an equivocal endorsement of -.12).

The final portion of Figure 9-2 contains the model of task structure derived by averaging the path weights across the five experiments. Curvilinear, linear or unpredicted paths which emerged for a single experiment were treated as "outliers" and not included in the computation of the average structure. Each identified path thus reflects data from at least four of the five experiments. The resultant model is a robust depiction of the

structure underlying the game. It warrants closer examination and a few explanatory comments.

The measure of intention shows appropriately opposed linear relationships with the two action systems. The slightly stronger relationship with the plankton action system suggests intention had a stronger influence on performance of the plankton task. Intention and both action systems have a positive influence on motor output. Although the intention to perform the plankton task increased the number of directional changes, following the rules for kayak crashing exerted a separate positive influence on the motor output system. This counters arguments suggesting the kayak task was best performed by not changing the whale's direction. The strongest influence on the motor system, however, is the exponential increase caused by the plankton action system.

Examination of the influences on the criteria is also interesting. Intention, action and motor output measures combine to explain 58 percent of the variance in the kayak task. By most standards this would be considered not only adequate but impressive. The intention and action systems each explain nearly equal portions of the variance in kayak crashing and the motor output system contributes an additional half measure. The contribution of the motor output system is, however, positive and nearly twice as great as its corresponding contribution to the plankton task.

The explanation the model provides for achievement of the plankton criterion is strong by any standard (R^2=.87). The strength of this regression is particularly striking because each performance measure is strictly independent of the criterion (e.g.,

actual scoring occurrences were excluded from the "less than three" measure). The strongest influence was the plankton action system. The curvilinearity of the relationship suggests the influence of the action system increases exponentially as its value increases linearly (i.e., the highest level of concentration yields by far the best results).

This review of the raw data contains several important pieces of evidence. The performance of both tasks is suspended well clear of both ceiling and floor effects. The average number of directional changes (one every 2.5 seconds) suggest the game was very interactive and depended heavily on real-time processing of information gleaned from the rapidly changing (every 700 msec) task environment.

The multiple performance measures showed close and consistent correlations with each other and their respective criteria. However, for rules related to the performance of the kayak task, subjects' post-game espoused strategies appeared to be almost completely independent of their behaviour. The consistently close correspondence between performance of the plankton task and subjects' espoused strategies appears rather bland and uninteresting compared to the kayak task.

Combining hierarchic assumptions and multiple performance measures yielded a model of the underlying task structure which is both useful and relatively robust. The model's independent auxiliary performance measures explain 87 percent of the variance in the plankton task and 58 percent for the kayak task. This model is interesting in its own right, but also provides a meaningful context for its components. The hierarchic structure of this model

is assumed by the analyses which follow.

9:4 BETWEEN-SUBJECTS ANALYSES

The summary of between-subjects analyses for Experiments One, Two, Three and Five are shown in Figure 9-3. As no individual differences were collected from Experiment Four, data from this experiment was excluded from the summary. Each of the individual difference values shown in Figure 9-3 reflects the average of all the experiments during which the measure was taken. Reaction time and incidental learning measures were collected from all four experiments, embedded figures scores from three experiments and the validity of espoused strategies from two. The correlation matrix similarly contains averages across all experiments involving the respective measures.

A slightly different approach was taken for combining the regression equations. Unmatched samples of subjects and alternative combinations of individual difference measures resulted in the emergence and subsequent disappearance of several curvilinear and and interactive terms. It was very difficult to combine the resultant equations in a simple but meaningful form. The summary of regression equations is thus only an enumeration of the terms which made significant contributions to each of the measures of performance. Each replication of a particular term is marked by an asterisk (i.e., -RT** implies RT made a significant contribution for three of the four experiments).

Four measures of individual differences were employed. The 4-choice reaction time measure (RT) was taken from subjects' pregame performance. The other three measures were obtained from instruments administered after the game and were discussed in

SUMMARY OF
BETWEEN-SUBJECTS ANALYSES: DESCRIPTIVE STATISTICS,
ZERO-ORDER CORRELATIONS AND REGRESSION EQUATIONS
EXPERIMENTS ONE, TWO, THREE AND FIVE

Variables	Individual Differences RT	EF	IL	ES	Hierarchic Measures I LT3P	Ak CLQK	Ap PACTP	M MVST	Criteria K KDK	2K+P PTSB	P PEP
Mean	444	10.5	12.2	5.3	115	6.3	.427	67.2	11.0	32.0	25.9
SD	62	4.2	2.2	1.6	15	1.4	.091	13.5	2.7	9.8	12.8
Correlations:											
RT		-.34	-.33	-.16	-.32	-.52	-.61	-.66	-.67	-.64	-.63
EF			.36	.17	.32	.39	.37	.44	.39	.39	.41
IL				.12	.36	.49	.54	.56	.54	.57	.52
ES					.06	.24	.40	.31	.35	.40	.36

Summary of Regression Equations

$$I = -RT + EF \quad R^2 = .30$$

$$Ak = -RT + IXE + ES^2 \quad R^2 = .52$$

$$Ap = -RT^{**} + IL + ES \quad R^2 = .55$$

$$M = -RT^{**} + IL^{*} + EF^2 + ES \quad R^2 = .65$$

$$K = -RT^{**} - EF + IL + ES \quad R^2 = .62$$

$$P = -RT^{*} + IL^{*} + RXL + ES \quad R^2 = .61$$

$$PTS = -RT^{**} + EF^2 + IL^{**} + ES \quad R^2 = .65$$

* replications

Variables: RT= Four-choice reaction time; EF= Embedded figures test score; EF^2= Non-linear aspects of EF; IL= Incidental learning; RXL= Interaction between RT and IL; IXE= Interaction between EF and IL; ES= Correspondence of Espoused Strategies; ES^2 Non-linear aspects of ES; I= Intentions (less than three spaces); Ak= Kayak Action System (centre, not lined-up, one quadrant); Ap= Plankton Action System (one space less three spaces); M= Motor Output System (changes of direction); P= Plankton eaten; K= Kayaks destroyed.

Figure 9-3

greater detail in Chapter Two and the separate methods sections.

In general, subjects were relatively quick and, as the small average standard deviation suggests, fairly homogeneous in their performance of the 4-choice reaction task. Both the distribution of scores and average reaction time decreased when the subject sample was restricted to "students or equivalent." The embedded figures measure showed similar improvement when more stringent selection criteria were imposed. The incidental learning measure reflects the number of correct responses to 20 post task computer-generated questions. The mean score was 61 percent with a standard deviation of 11 percent.

The final individual difference measure reflected the validity of subject's espoused strategies for performing the two tasks. Although the overall validity of strategies for the plankton was much higher than it was for the kayak task, the variance for the two measures were nearly identical. Thus their sum reflects equal contributions from the two validities. The generally low correlations among these measures of individual differences (.36<r<.12) suggest they were realitively independent of one another.

Being "priority-specific," the hierarchic measures all reflect appropriate improvements when compared to the raw measures in Figure 9-2. When the criteria are converted to percentages of optimal scores (i.e., KDK=20, PTSB=75 and PEP=90), the means represent performance at 55, 43 and 29 percentages of the respective optima. The standard deviations are about 15 percent of the possible range for each of the conditions. This suggests each condition showed approximately the same amount of variability due

to individual differences. The two tasks (and three conditions) were, thus, very similar in terms of their potential sensitivity.

The correlation matrix confirms the results of analyses from the separate experiments. Reaction time (RT) was the best overall predictor of performance. Other than the rather weak relation with the intention indicant, reaction time provided strong predictions of performance for each of the other measures. There is no indication RT was a better predictor of performance on the plankton task (r=-.63) than on the kayak task (r=-.67). (This provides convergent evidence against the argument that the plankton task was more dependent on motor skills).

The other measures show slightly less predictive utility. The misapplication of the embedded figures instrument to non-naive subjects in Experiment Five depressed its correlations with the performance measures. The incidental learning indicant provides surprisingly strong correlations with the performance measures. Again there is no clear pattern showing closer relations between this measure and performance in any of the priority conditions. Although not as strong as the correlations between the criteria and other individual difference measures, the validity of espoused strategies is clearly positive. All the individual difference measures are more closely related to the performance criteria than they are to each other.

The summary regressions in Figure 9-3 add little to the simple pattern reflected by the correlations. The measure of intention (less than three spaces from the plankton during plankton priority trials) is the least well explained measure. The remaining measures reflect significant and nearly equivalent

contributions from all the measures of individual differences. From the data presented here, it would be difficult to construct an argument that any of the measures reflected any of the individual differences exclusively. No single measure of individual differences made consistent significant unique contributions to any of the performance measures.

In fact, the data warrant a somewhat different explanation. Subjects are each imbued with a variety of capabilities which may be separated by rigid contextual constraints (i.e., as with each of the individual difference measures). However, when these constraints are relaxed and subjects are allowed more freedom to develop their own ways and means to achieve intended goals, the distinctions between separate capabilities evaporate.

Although the between-subjects analysis did not successfully separate the contributions of independent measures of individual differences, it served a more general purpose. Both tasks were performed better by subjects who were quicker and better able to answer post-task questions. To a lesser extent, subjects who were field independent and espoused fewer inappropriate strategies also performed the tasks better. Although there were several interactions and curvilinearities, the effects of individual differences on performance are largely independent and intuitive. The strength and consistency of these contributions suggest the game and both its subtasks were not too different from other everyday activities. Such similarity supports the ecological validity of the task and the tentative extension of findings to other activities.

9:5 WITHIN-SUBJECTS ANALYSES

The most important analyses (particularly of the last three experiments) concerned within-subjects variance. Standardizing values in terms of each subjects' performance allowed direct comparisons of effects on the various performance measures. It also provided a common metric which allowed data from subjects performing at different levels to be combined meaningfully. The summary analyses to be presented here involve the original standardized data. However, the side tasks were all converted to scores which ranged between zero and one to increase comparability. Curvilinear and interactional terms were de-emphasized in order to focus on main effects.

Figure 9-4 contains a summary of the main effects from all five experiments. All values are in terms of subjects' standardized scores (i.e., z-scores based on their performance of all trials). This allows meaningful horizontal comparison of different performance measures. Main effects of priority and practice are averaged across all five experiments and presented in the first two rows.

The next six rows of data reflect the influences of six side task conditions after the main effects of priority and practice had been accounted for. All side tasks were recoded so their presence was valued "1" and their absence "0". For the memory load side task, the moderate 3-letter load was coded .5 as was the 45 msec temporal decrement. This allows vertical comparison of side task effects for each dependent measure. All factors involved in a particular experiment were entered simultaneously in the regression equations. This implies that each value shows the average

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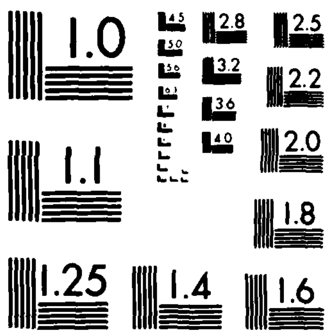

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

SUMMARY OF MAIN EFFECTS ON STANDARDIZED PERFORMANCE MEASURES FOR EXPERIMENTS ONE THROUGH FIVE

INDEPENDENT INFLUENCES	PERFORMANCE MEASURES					
	Intention	Action		Motor	Criteria	
	LT3	CLQ	PACT	MVS	KD	PE
Priority (low to high) Experiment 1-5	2.17	1.39	1.69	1.35	1.48	1.98
Practice (one hour: 18 tr) Experiment 1-5	.20	.50	.53	1.08	.70	.67
Randomized Articulatory suppression Experiment 4	-.11	-.15	-.29	-.67	-.20[a]	-.41
Speed - 90 msec decrease avg cycle Experiment 5	(.02)	(-.31[b])	(-.14)	-.47	(-.10)	-.34[c]
Memory load 0 to 5 letters Experiment 3	(-.15)	(.02)	-.20	-.40	(.05)	-.29
Paced Articulatory Suppression (1.5 sec) Experiment 4	(-.03)	(.03)	(-.11)	-.39	(-.04)	-.18
Unpaced Articulatory Suppression (3/sec) Experiment 5	(-.04)	(-.09[b])	(.05)	-.16	(.02)	(-.03)
Semantic Contents of Articulation (dir) Experiment 4	(.01)	(-.06)	(-.03)	(-.05)	(.05)	(-.05)

a - interacted significantly with practice
b - overall regression equation was not significant
c - interacted significantly with curvilinear effect of priority
()- effect was not significant in original analysis

Figure 9-4

influence across all other conditions. Each influence will be discussed.

The effect of priority was clearly pre-eminent. Subjects did what they were instructed (and presumably intended) to do. The values reflect the standardized changes caused by shifts from low to high priority. (Scoring for the kayak action system and criterion were reverse coded.) Figure 9-4 suggests changes from low to high priority caused a 2.17 SD shift in the amount of time subjects spent near the plankton. Although there was some variation from one experiment to the next, the shift to or from the equal priority condition was approximately 1.1 SD.

Among the other performance measures, the effects of priority were greater on the plankton task than on the kayak task. In general, the effects of instructionally-induced effort on the kayak task was only about 75 percent as great as the corresponding effect on the plankton task. The weakest effect of priority was on the motor output indicant, the number of directional changes.

Figure 9-4 does not contain information concerning the curvilinear effects of priority on performance. As was discussed in several of the chapters describing the experiments, this measure was strongly influenced by the "bias" during equal priority trials. Because biases changed from one experiment to the next, direct combination of values is not appropriate. The pattern of these influences is nonetheless interesting.

In Experiments One and Five, the plankton task showed significantly positive curvilinear influences from increased priority (i.e., increases from moderate to high priority were more productive than increases from low to moderate levels). In

Experiments Two and Five, the opposite pattern was significant for the kayak task (i.e., increases from low to moderate priority were more efficacious than increases from moderate to high priority). These data suggest different types of performance resource functions underlying the two tasks as proposed in Chapter Five.

The effects of practice are also interesting. Each of the values show the standardized effect of one hour's practice (i.e., 6 trials of each of the three priority conditions). The pattern of effects differs from the one produced by priority manipulations. Appropriately, practice has almost no effect on the intention indicant but a strong effect on motor activity. Practice also has strong but nearly equal effects on the two criteria and to a lesser degree their respective action systems.

Interactions between practice and priority are also interesting but direct combination of scores was problematic. A review of the within-subjects analyses from the five experiments provides useful information, however. Interactions were significant factors in predicting achievement of the plankton criterion in 4 of the 5 experiments. For the kayak task these interactions were significant for only two of the experiments. Within-subjects regressions for Experiment Five included significant interactive terms for each of the measures.

These results suggest subjects' intentions were more likely to mediate the effects of practice on criteria achievement than on other measures. This effect was more pronounced for the plankton task than the kayak task. Practice improvements in kayak task performance were distributed across priority conditions, but in the plankton task, benefits tended to accrue mostly in plankton

priority trials.

The next six rows of data contain the main effects of the side tasks from the last three experiments. The scores reflect standardized effects of the side task across all other conditions (i.e., practice, priority and other side tasks). Interactions were extremely rare; the two that occurred are marked by superscripts. Although the emphasis is on the size rather than the significance of effects, in general, shifts of about .15 SD were significant at the .05 level. Contributions which were not significant in the independent analyses of the experiments are listed in parentheses. Side tasks are listed in the approximate order of their effect size.

Paced, randomized articulatory suppression had the strongest effect on the number of directional changes. It appears the effect on the plankton task is about twice as great as the effect on the kayak task. However, the significant interaction between practice and randomization for the kayak criterion is important. During the second set of experimental trials, randomization did not interfere with performance of the kayak task. Because the main effect is an average across all conditions, the interference to the two criteria during the first set of trials was nearly the same. However, the effect of randomization on the two tasks was very different during the second set of trials; interference with the plankton task continued but disappeared altogether for the kayak task.

The next row shows the effect of a 90 msec decrease in the average cycle time (i.e., a 13 percent increase in the game pace). The effects on the plankton task are similar to those of randomization but decreased considerably for the kayak task. The

interaction between game speed and the curvilinear aspect of the influence of priority (i.e., a concentration bonus) is important. Time makes exponentially greater contributions to the plankton task as priority increases. The lack of effect on the plankton action system is curious. Apparently even at the fastest pace, subjects could maintain nearly the same proportion of time one space away from the plankton. Time had a stronger effect on actual scoring than on staying in position to score. The overall effect of time on the kayak task was equivocal. Inspection of performance plots suggested that although extra time generally facilitated performance, the effect was reversed under conditions of high priority and low practice. In this condition, extra time resulted in worse performance.

Verbal memory load did not interfere with the kayak task. In fact, the overall effect of this side task was facilitatory. (Closer inspection revealed these facilitatory effects were again most pronounced under conditions of low practice and high priority.) Memory load, however, had significant negative effects on the plankton action system, motor output system and the plankton criterion.

Paced articulatory suppression's effect on the number of directional changes was similar to the 5-letter memory load. It also significantly interfered with the plankton task but did not have a significant effect on the kayak task. Although the overall effect of paced articulation on the kayak task was slightly negative, within the high priority trials, the effect of the side task was again positive.

The effect of the next two influences (unpaced articulatory

suppression and the semantic contents of articulation) on both criteria was negligible. However, unpaced articulatory suppression interfered significantly with the number of directional changes. This dissociation of motor output interference from criterion achievement is important because it weakens alternative explanations based on the differential sensitivity of the two tasks to motor-output intrusions. Motor decrements do not necessarily diminish performance on the plankton task.

Combining the results of the within-subjects analyses from the five experiments yields interesting results. The measure of intention is strongly influenced by priority instructions but is relatively impervious to other independent influences. In contrast, the motor output indicant appears vulnerable to intrusions of all sorts. Both action system indicants show influences similar to but slightly weaker than their respective criteria.

Criteria for the two tasks show different patterns. Plankton performance is strongly influenced by verbal instructions and most improved by the shift from moderate to high levels of priority. Although practice has a positive effect, this is generally mediated by priority. All substantive side tasks (i.e., those assumed to involve intermediate cognitive processing) caused significant interference. None of the four conditions which interfered with plankton performance, however, interacted significantly with practice. "Processing time" showed a significant interaction with the positive curvilinear aspect of priority's influence. Although unpaced articulation interfered with motor activity, it had virtually no effect on the plankton criteria.

Performance of the kayak task was also strongly influenced by priority but greater benefits accrued with shifts from low to moderate levels than with shifts to high priority. Practice had almost the same relative effect on kayak and plankton performance but its effect was less moderated by priority for the kayak task. The single factor causing significant interference with the kayak task performance, randomized suppression, was significantly ameliorated (i.e., obliterated) by 30 minutes' practice. There is also evidence to suggest the lesser verbal side tasks actually facilitated kayak performance under conditions of low practice and high priority.

9:6 SYNTHESIS

Explanation is the object of empirical inquiry. The adequacy of an explanation rests on two criteria. Explanations must both correspond to the evidence and be internally coherent. Elegance and parsimony are hallmarks of coherence. Since an explanation is the synthesis of evidence and theory, several salient features of both will be recapitulated.

The relevant evidence was derived from subjects' performance of an interactive arcade-type video game. The theoretical importance of this novel psychological instrument warrants comment. The issue of ecological validity was introduced in the first chapter. It was argued that activities occurring in meaningful contexts and placing substantive demands on human information processors are more representative of the important tasks which comprise everyday life.

The Save the Whale game developed in these experiments was both engaging and demanding. During the game, subjects controlled

the direction of movement of a blue whale by pressing one of four discrete computer keys. Two distinct tasks were combined under three symmetrical priority conditions (i.e., low, medium and high). The difference in these two tasks is fundamental. One task involved matching the whale's movements to the psuedo-random path followed by a small mass of flashing plankton. Points were scored each time the whale and the plankton were co-located. This task was very simple but because it was uncertain (i.e., unpredictable), it involved substantive information processing.

The other task was much more complicated. At constant but irregular times, kayaks appeared at the screen boundary and moved inexorably toward the whale. If a kayak encountered one of the 18 icebergs on the screen, it crashed and subjects gained points. However, if it reached the whale and harpooned it, points were lost. The substantive demands of this task were based on its complexity (it was possible for as many as four kayaks to be displayed at one time).

Although many features of the explanation which follow concern differences between these tasks, it is important to recognize ways in which the tasks were similar. Neither ceiling nor floor effects were factors in the performance of either. In terms of their respective potential ranges, both tasks showed nearly equal variability. Correlations with individual difference measures suggest quicker and brighter subjects enjoyed an equal advantage in performing both tasks.

The theoretical model to be imposed on these performance data was introduced in Chapter One. From the perspective of this model, tasks are represented as sets of unspecified parameters. The

unique function of intermediate cognitive processes is parameter specification. The model presented included three potential sources of specification which represented independent influences on motor activity and subsequently performance. Through explicit self-instruction, behaviour is directly influenced by activity in the intermediate verbal processing mechanism (i.e., the articulatory loop). Non-verbal attentional processing also influences performance but relies on other, more general but still limited intermediate processing resources (i.e., the central executive and its interactions with other intermediate slave mechanisms such as the visuo-spatial scratch pad). Task parameters can also be specified, and thus performance influenced by independent, parallel and relatively immediate reference to knowledge structures (i.e., mental models).

Although these influences often work in concert, attentional mechanisms (either verbal or general) are usually only brought to bear when parameters remain unspecified by knowledge structures. While verbal-processing can contribute to the performance of many tasks, its inherently abstract and symbolic nature preclude its contributions to many other tasks. Even for those tasks to which it does not directly contribute, the verbal mechanism may provide coherent verbal accounts (i.e., explanations, rationalizations or excuses). Thus the theoretical model of intermediate cognitive processes involves three separate and distinct sources of parameter specification: implicit knowledge and verbal and non-verbal attentional processing.

The model and the performance data can now be combined. Most of the pertinent evidence concerns the influence of different

exogenous variables on the performance of the two game tasks. However, the mention of two preliminary findings is theoretically important. The explicit strategies subjects espoused for performing the plankton task were consistent with their actual task performance. Although the strategies subjects propounded for the kayak task were consistent from one experiment to the next, they bore little correspondence to the pattern of activities associated with subjects' criterion achievement. For the plankton task, espoused and de facto strategies were nearly identical. Additionally, subjects rated the kayak task as being more "difficult" (and to a lesser degree more complex and uncertain) than the plankton task.

The close correspondence between explicit knowledge and performance of the plankton task suggests the intermediate processes involved are largely accessible to verbal mechanisms. The lack of correspondence for the kayak task suggests the relevant intermediate processes are not available for verbal report. It is noteworthy that although subjects apparently have no direct access to the processing activities involved in the kayak task, they have no hesitation in proclaiming its greater "difficulty".

The evidence concerning independent influences on the two tasks elaborates the theme set down by the preceding observations. Shifts in priority from low to moderate priority levels are about equally productive for both tasks; subsequent shifts from moderate to high levels show a marked difference. The marginal utility of this shift increases for the plankton task but decreases for the kayak task. If one assumes that the shift to high priority involves proportionately more explicit verbal inputs, this evidence

implies intermediate verbal processing contributes more to the plankton task than the kayak task. Although practice improves the performance of both tasks, its effects are much more likely to interact with (i.e., be mediated by) priority instructions for the plankton task. Again, this suggests intermediate verbal mechanisms contribute more to the plankton than the kayak task.

A variety of verbal side tasks were combined with the game. Because the game was predominantly a visuo-manual activity, it was assumed auditory-verbal side tasks would minimize peripheral interference. The assumption underlying the dual task approach is that exogenous activities will occupy, consume or otherwise restrict the availability of either or both intermediate processing mechanisms (i.e., verbal or non-verbal).

Randomization was assumed to affect primarily general processing while the temporal manipulation was expected to affect both verbal and non-verbal intermediate processing mechanisms equally. Memory load and fixed sequence articulatory suppression side tasks were employed to involve specifically the articulatory loop. Unpaced suppression involved more motor activity than any of the other side tasks but because it was repetitive and well practised (i.e., automated), it placed only minimal demands on intermediate processing mechanisms. There was no direct manipulation of implicit knowledge, however, significant interactions between observed interference and practice would indirectly suggest automatization and thus the influence of implicit knowledge.

The plankton task was simple but uncertain. Unpaced articulatory suppression was the only side task which did not

impair subjects' performance of this game task. All other verbal side tasks involving either the articulatory loop or central executive caused significant and linearly additive negative effects. None of the factors causing interference was significantly ameliorated by practice. These findings suggest both the articulatory loop and central executive contributed to performance but implicit knowledge did not have a significant influence for the plankton task.

A formulation which fits these data is that the plankton's inherent uncertainty required active processing. Uncertainty (i.e., the lack of consistent underlying structures) also prevented subjects from developing useful internal representations. Thus implicit knowledge made relatively few contributions to performance. Its simplicity, however, made this task amenable to verbal report and thus accounts for the close correspondence between explicit knowledge and actual performance.

The kayak task was based on many consistent relationships; it was very complex but relatively certain. This task was unanimously nominated as being more "difficult" than the plankton task. The kayak task was surprisingly impervious to interference from verbal side tasks. Side tasks involving either the articulatory loop or the motor output system had no significant general effects. In fact, under conditions of high priority and low practice (when self-instruction might be expected to be particularly prevalent), several side tasks showed clear signs of actually facilitating performance. This suggests the effect of the articulatory loop was at best irrelevant and at worst noxious to performance of this complex but certain task.

The randomization side task caused significant disruption in the kayak task as well as the plankton task during the initial trials. This suggests a positive contribution from general non-verbal processing. However, with practice, interference from even this very demanding side task disappeared completely. Since the side task continued to interfere with the plankton task, it is assumed that performance of the kayak task became automated (i.e., its performance was influenced by the direct specification of required parameters by implicit knowledge).

These results contrast sharply with those reflecting the performance of the plankton task. The kayak task's inherent complexity rendered it inaccessible for verbal reports. This accounts for the complete lack of correspondence between subjects' espoused and de facto strategies. However, because the task was based on consistent structure-relations, its performance could be automated. Such automation occurred, although the relationships were never available for explicit verbal report.

Simply put, the story is this: different tasks are processed differently. Rated difficulty does not necessarily reflect the involvement of limited-capacity intermediate processing mechanisms and thus is not a particularly useful metric for predicting side task interference. Differences in interference patterns reflect differences in the structure of the tasks themselves. To the extent the task is simple or "salient," explicit verbal knowledge is likely to be consistent with performance and therefore facilitatory. If a task is too complex (i.e., the number of parameters exceed the capacity of working memory), explicit verbal knowledge may not correspond to actual performance and thus is

unlikely to contribute significantly to performance. To the extent the task's underlying structures are consistent, they will be internalized in the form of mental models. Though not necessarily available for verbal report, such implicit representations can facilitate performance greatly by directly specifying required parameters. This, in turn, obviates the involvement of other limited-capacity, intermediate, processing mechanisms.

A FUNCTIONAL EXAMINATION OF INTERMEDIATE COGNITIVE PROCESSES

CHAPTER TEN

CONCLUSIONS, IMPLICATIONS AND RESEARCH OPPORTUNITIES

10:1 INTRODUCTION

This thesis began with the development of a general information processing model which served as the conceptual framework for a novel experimental tool. Procedures for employing the tool empirically and analysing the resultant data also relied on the theoretical structure provided by the general model. Five experiments, each with convergent analyses, were accomplished. Data from these were combined and summarized in the previous chapter. A synthesis of the empirical results and original model was then presented. Not too surprisingly, the data fit the model well. Indeed, so many theoretical formulations are available, it is difficult to produce results that don't fit some model.

> Unfortunately, an understanding of human mentality is not to be achieved merely by carrying out experiments - no matter how exemplary - and developing theories to account for their results. That is the hard truth and one that is only just beginning to be learnt... The explanation of experimental results has often been taken as the actual goal of psychology. It is a poor substitute for understanding human behaviour and mentality. (Johnson-Laird & Wason, 1977, p.2)

The final chapter of this thesis addresses broader issues. First the empirical particulars of these studies will be stripped away and the remaining abstract conclusions presented. These findings are relevant to several current debates in cognitive psychology. Implications concerning alternative conceptualizations of the human information processing system and the structure, acquisition and application of knowledge (i.e., internal

representations of external structural relations) will be discussed. Together the conclusions and their theoretical implications suggest several priorities for further research. These will also be presented briefly.

10:2 CONCLUSIONS

The similarities and differences between two specific game tasks were the central feature of these studies. Both tasks were embedded in a meaningful context and placed substantial demands on the human information processing system. The tasks were performed under virtually identical conditions. Individual difference data suggested quick and bright subjects enjoyed considerable and nearly equal performance advantages on both tasks.

Traditionally the gap between problem solving paradigms and empirically-preferred, "small and simple" laboratory tasks has been rather wide. Games such as chess (de Groot, 1965) or problems such as cryptarithmetic (Bartlett, 1958), missionaries and cannibals (Greeno, 1974), or the Tower of Hanoi (Simon, 1975) have been used to investigate "higher" cognitive processes. More recent studies have dealt with the "control of dynamic systems" in which success depends on maintaining as well as reaching designated criteria (e.g., Berry and Broadbent, 1984; Broadbent, Fitzgerald & Broadbent, 1986). One difficulty with these decisional paradigms, however, is the availability and adequacy of collateral explanatory measures of performance. Simon (1979) labels this the "density of observation" problem. Criterion indicants alone often do not provide sufficient information to support plausible explanations of the processes involved.

The arcade game format also introduced external "pacing".

Because the computer accepted subjects responses (or the lack thereof) every 700 msec, subjects' increased decision latencies directly affected their performance. Additionally, simultaneous objective measures reflecting performance at the psychomotor, tactical and strategic levels was recorded every cycle. In this respect, these experiments are an extension of the dynamic control system paradigm to tasks involving on-line, real-time skills as well as decisional activities. In short, subjects' own performance was to constitute an important part of the problem to be solved.

Three classes of differences between the two experimental tasks are important. Within the constraints of 1) relying on the same displays and controls and 2) being performed at levels free from ceiling and floor effects, the two tasks were as different as possible. Differentiation was introduced to structural as well as superficial aspects of the tasks. Subjects' verbal reports concerning the tasks were also different. Both evaluations and explanations (i.e., post hoc protocols) show clear differences between the tasks. The final type of difference involved the actual performance of the two tasks. Several exogenous influences (viz., priority instructions, practice, game pace, and an array of concurrent verbal side tasks) were examined. Together, the pattern of these differences has interesting implications for several contemporary information processing theories. The interpretation of all subsequent differences, however, depends on understanding the structural differences between the two tasks.

A task can be represented as a number of parameters, each of which must be filled if the task is to be accomplished. The demand a task places on the information processing system is the product

of two factors: the number of its parameters and the rate at which they must be filled. The number of parameters involved in a particular task reflects its complexity (i.e., complex tasks involve many parameters). The rate at which parameters must be filled reflects the task's uncertainty (i.e., uncertain tasks are inherently unpredictable; parameters must, therefore, be continually respecified). Tasks that are neither complex nor uncertain are trivial and place no substantive demands on the human information processing system. Tasks that are both complex and uncertain may overwhelm the processing system and render performance above the level of chance impossible. (Holding (1981) suggests similar dimensions for differentiating human skills.)

A number of tasks which place moderate demands on the human information processing system lie between the extremes. Although tasks with moderate levels of both complexity and uncertainty are prototypical, values along these two dimensions do no t neccesarily coincide. In fact, the greatest substantive difference between tasks occurs among tasks with moderate demands. The two ideal task types are those that are simple but uncertain (Type A) and those that are complex but certain (Type B). Each of these types was incorporated in the game. (Eating plankton was a Type A task and wrecking kayaks, a Type B task.)

Subjects' verbal reports reflected other important differences. Subjects accomplished three types of verbal reports following the game. One involved answering computer-generated questions about different aspects of the game (e.g., recognition of characters, sounds and structural relationships). Although subjects who performed better during the game also selected more

correct responses to these questions, there was no clear relationship between particular types of questions and the performance of either task. Two other types of post task verbal reports, however, distinguished the tasks: subjective ratings and espoused strategies.

Subjects rated three priority conditions (i.e., two in which each type of task was high priority and one in which the two tasks were to have equal priority) on three dimensions: difficulty, complexity and uncertainty. Although, the average rating of the equal priority condition was the highest on all these dimensions, the most pronounced difference was between subjects' ratings of the two high priority conditions. The Type B (complex but certain) task was rated as being much more difficult than the Type A task. Although the Type B task was also rated as being both more complex and uncertain than the Type A task, these differences diminished considerably.

The other type of verbal report showing a difference between the tasks involved the validity of subjects' espoused strategies. Many measures were taken as subjects played the game. Together these measures accounted for nearly 90 percent of the total variance in the Type A task and about 60 percent in the Type B task. Some of these measures reflected activities that could be expressed by explicit verbal rules. Subjects were asked to rate each of several such rules as being positively related, negatively related or unrelated to criterion achievement. Subjects also indicated the two most important rules. These "espoused" ratings were then compared to the objective correlations between activities reflecting these rules and criterion achievement. For the Type A

task, the consistency between what subjects said and did was striking. The rules subjects espoused were entirely valid.

In contrast, there were pronounced inconsistencies between the espoused and de facto strategies for the Type B task. Subjects rated the most important rules as being unrelated to success, irrelevant rules as being important and even gave moderately strong endorsements to activities which showed substantial negative relationships to criterion achievement. The rules subjects espoused for the Type B task were generally not valid.

These instruments were only administered during two experiments (Three and Five), but subjects' average responses were nearly identical. This is particularly interesting in the case of the Type B task. Although espoused ratings were apparently unrelated to subjects' performance within either experiment, both task performance and espoused ratings were very consistent across experiments.

The most crucial differences between the tasks were in their performance. Both tasks responded to changes in priority instructions and showed nearly equal relative improvements with practice. However, priority had a slightly stronger direct effect on the Type A task and also significantly mediated (interacted with) the effects of practice. Additionally, there was evidence the relationship between priority and performance was positively accelerated for the Type A task but negatively accelerated for the Type B task. (Shifts from low to moderate priority were more beneficial for the Type B task but shifts from moderate to high priority were the most beneficial for the Type A task.)

The pattern of influences caused by the other exogenous

influences is also very important. Neither task was affected by the concurrent performance of a side task involving only repetitive verbal output. Nor was either task affected by the semantic relevance of the material to be articulated. The requirement to produce randomized verbal responses at a fixed rate initially caused almost identical disruption in the two tasks. The most interesting differences occurred within the range established by the factors that caused no interference with either task and the one that interfered equally with both.

The simple but uncertain Type A task showed significant interference from all substantive concurrent verbal side tasks. Memory loads of 3 or 5 letters or paced articulation of either numbers or directional words significantly interfered with its performance. Increasing the game pace by 45 or 90 msec also caused significant decrements in the performance of the Type A task (particularly under high priority conditions). The decrements caused by each of these influences endured over periods of about one hour.

In contrast, the complex but certain Type B task (the one overwhelmingly nominated by subjects as being more difficult) was impervious to all these exogenous influences. There was even evidence that under conditions of high priority and low practice, moderate verbal side tasks or less processing time facilitated performance of the Type B task. Although the extremely demanding randomization side task caused significant interference initially, its negative effects on performance completely disappeared after 30 minutes practice.

These findings support the following general conclusions:

1) The explicit strategies subjects selected for the simple Type A task were consistent with their performance, but for the complex Type B task, espoused and de facto strategies were inconsistent with performance.

2) Subjects nearly unanimously nominated the Type B task as being more difficult than the Type A task.

3) Side tasks involving only repetitive peripheral motor outputs did not interfere with either type of task.

4) Side tasks involving intermediate verbal processing interfered with the performance of the Type A (simple but certain) task but not the Type B (complex but certain) task.

5) None of the side tasks which interfered with performance of the Type A task was significantly ameliorated by practice.

6) A side task placing heavy demands on general, non-verbal intermediate processing interfered with both types of task.

7) This interference was obliterated by 30 minutes practice for the Type B task but continued to be significant for the Type A task.

10:3 IMPLICATIONS

Two distinct attitudes toward mind have competed throughout history. The Greek poet Archilochus contrasted those who view intellect as a single entity ("hedgehogs") with those who favour its fragmentation into several components ("foxes") (from Berlin, 1953). Hedgehogs assume humans are endowed with a singular and inviolable mental capacity. In contrast, foxes maintain several separate capacities must be combined to adequately represent human mentality. These alternative views were reflected by the debate which raged between those (following Charles Spearman) who posited a general factor of intellect, and those (following L.L. Thurstone)

who propounded several separate mental abilities, with none pre-eminent among them (Gould, 1981).

This distinction is also reflected by two theoretical positions which polarize contemporary human information processing theories. The hedgehog camp supporting the fundamental importance of a central processor of limited capacity includes many contemporary researchers and theorists (e.g., D.E. Broadbent, D. Kahneman, D. Norman and A.T. Welford). The fox camp, stressing the multiplicity or modularity of intermediate cognitive processes also has many champions (e.g., A.D. Allport, P. McLeod, D. Navon and C.D. Wickens). Many of the efforts to present conclusive arguments in favour of one position or the other have involved data derived from the concurrent performance of two tasks. Two factors concerning the patterns of interference reflected by such experiments differentiate the two perspectives: task difficulty and task similarity. Unfortunately, neither term enjoys a consensual operational definition.

From the central capacity perspective, task difficulty directly reflects informational demands placed on a general processing system. Thus, tasks that are more "difficult" involve more information and are predicted to both cause more interference with other tasks and also be more susceptible to interference from concurrent processing activities. The increased interference caused by the "similarity" between two concurrent tasks is assumed to reflect mostly competition for the same satellite (i.e., peripheral) structures.

From the multiple resource view, the hypothetical location and relative importance of these two factors is reversed.

Interference caused by concurrent processing is attributed to competition for the same intermediate module or mechanism. It is assumed the structure of the task determines which particular mechanisms are required. The effects of difficulty occur within a particular common processing resource. The most extreme position suggests no resources are necessarily common to all intermediate processing activities (e.g., Allport, 1980 or Wickens, 1984b).

Thus dissimilar tasks which show appreciable interference when accomplished together support the hedgehog position. Demonstrations of two difficult but dissimilar tasks being performed concurrently without interference cause elation among the foxes. It is surprising the debate is yet to be resolved; the two positions make distinctly different predictions concerning patterns of interference to be observed in dual task performance. Both camps have produced results embarrassing to those holding the alternative view, but an irrefutable positive demonstration of either extreme position does not exist.

The conclusions presented here are consistent with this general trend: they contain evidence damaging to both extreme positions. The task unanimously selected as being the more difficult, was the least sensitive to side task interference. In fact, some verbal side tasks even appeared to facilitate performance of this difficult, Type B task (a finding which is a plague upon both houses). The involvement of identical peripheral processes (i.e., visual presentation and manual responses) as well as the equal effects of individual differences on the two tasks, argue against peripheral interference explanations for the observed differences in performance. Similarly, the compatible results from

the direct manipulation of decision time excludes explanations which rely on volitional mediation or the misallocation of processing resources.

At least some intermediate processing components must be functionally distinct (i.e., contribute to one task but not the other). However, there is considerable conceptual distance between this finding and the assumption that the system is entirely "modular". In fact, the almost identical relative interference with the two game tasks caused by the most demanding (i.e., difficult) side task suggests the involvement of a very general intermediate processing resource of limited capacity. If one accepts the differential interference (and the initial logical arguments) as evidence of the extreme structural dissimilarity of the two types of tasks, then common interference is inexplicable from the position of extreme modularity.

The question is not one of choosing whether the central capacity model or the multiple resource model provides the better explanation for these data; neither is sufficient alone. The more appropriate question is how to predict when performance will be consistent with one alternative or the other. The results presented here suggest three factors are important: the task type (A or B), the side task type (general-nonverbal or verbal-specific), and the amount of practice subjects receive.

The simple but uncertain Type A task appears to fit the central capacity model under all conditions. The more difficult the side tasks, the greater the interference. Although the amount of interference decreased slightly with practice, no significant interactions with practice were observed. Perhaps the traditional

bias toward "small and simple" paradigms accounts for the continuing support central capacity models receive. The results with which experimental psychologists are most familiar (viz., their own) largely involve Type A tasks. The substantive demands of such tasks derive from uncertainty rather than complexity. Central capacity models are generally appropriate for these tasks.

The complex but certain Type B task provided evidence consistent with both the central capacity and multiple resource models. Interference depended on both the amount of practice and the type of verbal side task. With sufficient practice (i.e., 30 minutes) none of the side tasks interfered with the performance of the Type B task. However, initial interference depended upon the type of side task. Many side tasks which caused significant interference with the subjectively easier Type A task had no demonstrable effect on the Type B task. All these side tasks were assumed to demand intermediate verbal processing (i.e., the use of the articulatory loop). This successful concurrent accomplishment instantiates parallel functioning by multiple resources (i.e., Type B task performance did not involve intermediate verbal processing). However, when a side task assumed to place demands on general resources was used (i.e., randomization), initial interference to both types of task was identical. This suggests a common intermediate processing resource (i.e., the central executive) contributed to the performance of both tasks.

Much of the evidence and argument supporting modular formulations involves complex but well-practised activities (i.e., typing, reading, piano playing or auditory shadowing). For these Type B tasks (if practice is sufficient or the side task not too

demanding) multiple resource models provide better explanations than central capacity models.

The identification of conditions under which information appears to be processed in distinctly different ways is not new. Norman and Bobrow's (1975, 1976) differentiation of resource- and data-limitations fits these data well. (The Type A task is persistently resource-limited but performance of the Type B task with adequate practice or with moderately demanding verbal side tasks reflects data-limitations.) It has been widely recognized that practice alters the necessary intermediate psychological functions so that performance is less susceptible to interference from side tasks (Bahrick and Shelly, 1958; Wickens, Mountford & Schreiner, 1981). A variety of different conceptual formulations describe this phenomenon (e.g., Schneider & Shiffrin's (1977) automatic and controlled processes; Kinsbourne's (1981) functional cerebral space or Rabbitt's (1981) speed error tradeoff function). Knowledge, provides a common theme running through all these formulations.

The knowledge most relevant to performance is comprised of the enduring, internal representations of the relation structures underlying tasks. Three aspects of knowledge are of particular interest: its structure, acquisition and application. Issues relating to each will be presented before further implications are discussed. In the first chapter, several alternative epistemological dichotomies were examined (e.g., declarative vs. procedural, propositional vs. analog and continuous vs. discrete) and discarded in favour of the single dissociation between implicit and explicit knowledge. The purpose here is not to repeat the

arguments supporting this choice, but to examine alternative formulations concerning the structural relationship between implicit and explicit knowledge.

That there can be discrepancies between what subjects do and say is widely accepted (Nisbett & Wilson, 1977; Ericsson & Simon, 1980). However, theoretical accounts of such dissociations vary to a considerable degree. The most prevalent view is that explicit (i.e., verbally reportable knowledge is a fully-contained subset of a larger body of (implicit) knowledge. The alternative view (the one to be supported here) is that these data bases are separate and discrete. Although, it must be conceded that many functional linkages connect the two types of knowledge, the latter view posits much greater independence than the former.

The assumption that verbal reports can be represented as the tip of an epistemological iceberg is widely accepted. Assumptions of this relationship underlie many currently popular theories (e.g., Rumelhart, 1980; Johnson-Laird, 1983 or Fodor, 1983a). However, because these views are so widely accepted, they are not often explicated. Ironically, those opposed to this popular view, state it most clearly:

> The common sense view, which we wish to question, supposes people act by consulting an internal model of the world, a data base of knowledge common to all output processes, and manipulating it to decide on the best action. To handle the discrepancies between verbal report and action, this view also supposes a distinction between the general data base of knowledge, and other relatively specific processes that act upon this data base. Some such processes will result in verbal outputs, some in actions, and knowledge that is accessible through one process may fail to be revealed through another... (Broadbent, Fitzgerald & Broadbent, 1986, p.33)

Such a view of knowledge fits many experimental results and

is also consistent with the popular conceptualizations of how knowledge is acquired. Rumelhart (1980) suggests learning by accretion involves "memory traces of comprehension processes" (usually partial copies of instantiated schemata). After knowledge is acquired, "tuning" (i.e., the elaboration and refinement of concepts through experience) may take place but this is of secondary importance. Similarly, Simon's (1979) formulation of human problem solving stipulates that the requisite development of the initial problem space is an active conscious process. Anderson (1983) offers an even more extreme account of knowledge acquisition through the active compilation: "Knowledge in a new domain always starts out in a declarative form." (p. 219)

This view has important implications concerning the application of knowledge to task accomplishment (viz., performance). From this perspective, discrepancies between verbal reports and action reflect the inadequacies of verbal mechanisms to process other informational codes. This formulation accounts admirably for the most commonly observed dissociation between behaviour and explication (viz., improvements in performance without increases in the accuracy of verbal reports). This view, however, provides no account for the instances when knowledge appears to increase but performance does not or when knowledge and performance appear not only to be unrelated but negatively related. There are a growing number of empirical studies for which the tip-of-the-iceberg analogy is inconsistent with the evidence.

The belief that the ability to talk about certain activities and perform them well are negatively related is very popular outside academia. The adage: "those that can, do and those that

can't, teach" has been adopted by practioners in many occupations and professions. However, empirical demonstrations of this phenomenon are generally rare.

Hendricks' (1983) study of experienced and novice pilots "flying" a simulator with reverse-rigged controls aptly illustrates the negative relationship between explicit knowledge and performance. The experienced pilots would have almost certainly been able to answer questions concerning the flight or the most appropriate procedures to be followed even with reversed controls. As reported earlier, however, the experienced pilots' performance was much worse than the novices. Similarly Berry and Broadbent (1984) found a small but significantly negative relation between performance and answers to questions about the dynamic systems they had been controlling. Their subjects also demonstrated the more unusual type of dissociation in which verbal knowledge is improved through instruction but performance is unaffected. Broadbent (et al., 1986) had concluded from the results of earlier studies involving similar dynamic control tasks:

> ...that verbal knowledge has (a) data base of its own: within the limits of the variables we have examined, all effects appear to be on databases that are specific, and we do not seem to be affecting a common database.(p. 48)

The results of the experiments in this thesis provide evidence relevant to the relative independence of implicit and explicit knowledge. For one type of task, the overlap between what subjects did and said was extensive, but for the other task the dissociation appeared nearly complete. Subjects' were able to accurately identify the relationships between subsidiary activities and the achievement of the simple task. In contrast, subjects'

verbal accounts of the complex task showed almost a complete dissociation from their performance. In some cases commonly espoused relationships directly contradicted observed relations. The inconsistencies which occurred were not limited to trivial, lower-level aspects of motor activity; they involved critical tactical decisions. These findings are consistent with those of Reber and Kassin (1980) or Berry and Broadbent (1984) in suggesting task "salience" (i.e., the lack of complexity or the conspicuity of critical relationships) moderates the validity of verbal reports. The more complex the task, the less likely are the critical relations to be explicable.

Although both accounts provide explanations for dissociations between explicit and implicit knowledge, negative relations between performance and verbal protocols suggest independent data bases. Several authors from fields somewhat removed from experimental psychology have also noted the dissociation between verbal accounts and performance. Malinowski (1925) suggests that a great deal of verbal behaviour is ritualistic and occurs under conditions of high anxiety. He points out chants and other repetitive verbalizations (i.e., "ceremonial articulatory suppression") are frequently employed to produce calm in periods of heightened danger and tension. Shotter (1980) suggests language is primarily rhetorical rather than representational; verbal accounts serve important social functions independently of their correspondence to existing causal relations. Similarly Karmiloff-Smith and Inhelder (1977) provide a lucid explanation of how the construction of "false theories" or "overgeneralizations" can play a productive role in the acquisition of cognitive skills. As they suggest:

> Overgeneralization, a sometimes derogatory term, can be looked upon as the creative simplification of a problem by ignoring some of the complicating factors... counter examples alone do not induce change in behaviour... first a unifying rule must be formed. (p. 306, 301)

Broadbent (1985) suggests the relationship between verbal adages and implicit knowledge is useful but indirect.

> A plausible possibility is that procedures can be given verbal labels and processed in that form. Fancifully, proverbs can be seen as such labels: 'Too many cooks spoil the broth' and 'Many hands make light work' are not general truths, because they contradict each other. When a proverb is said or thought, it calls for one set of procedures for action rather than another... (p. 48)

This implies the accuracy of verbal knowledge (i.e., the extent to which it corresponds to extant structural relations) may be independent of its utility. This is particularly true when the important functional relationships are unclear (i.e., "non-salient") or so complex they exceed the capacity of explicit processing mechanisms. As Broadbent (et al., 1986) suggests:

> From the present state of knowledge, therefore, it would be unwise to assume that verbal knowledge is the ideal towards which the less explicit intuitive decision is developing. Rather performance based on verbalizable knowledge, and that which selects action by matching the situation to those met in earlier experience, may be alternative modes of function each with its own advantages. (p. 49)

Independent knowledge bases provide one explanation for the differences in the performance of the tasks. The differential validity of explicit knowledge provides an important moderating variable which should be included in the formulation of information processing models. The implicit assumption that explicit knowledge is accurate but incomplete becomes increasingly fallacious as tasks of increasing complexity (and ecological validity) are considered. Some of the things people say (and believe) about complex tasks are

quite simply untrue. The following discussion provides a number of ways in which this factor might affect other outcomes such as performance automaticity and rated difficulty. This discussion also identifies opportunities for further research.

10:4 RESEARCH OPPORTUNITIES

Knowledge is not unrelated to the earlier discussion of alternative conceptualizations of the human information processing system. In fact, independent knowledge bases provide a critical moderating variable between the task types and performance outcomes. Inaccurate or inappropriate explicit knowledge may nullify the contributions of attentional resources, particularly specifically verbal mechanisms. Also, the lack of consistency of structural relations prevent the development of viable internal implicit representations. A structure reflecting these relationships is depicted in Figure 10-1. Task uncertainty and complexity are the hypothetical dimensions employed to differentiate the two types of game task. These factors are exogenous to the other model components; however, differences in the two can only be indirectly examined through the tasks.

Three separate outcomes were considered: 1) the objective validity of subjects' espoused strategies, 2) subjects' ratings of task difficulty and 3) performance automaticity (viz., lack of side task interference). The model suggests the combined influences of high uncertainty and low complexity increase the validity of espoused strategies. These influences seem plausible. High uncertainty requires attentional processing and low complexity enables it (i.e., provides adequate capacity for actively processing or "attending to" the critical task parameters). The

PROPOSED CAUSAL RELATIONS

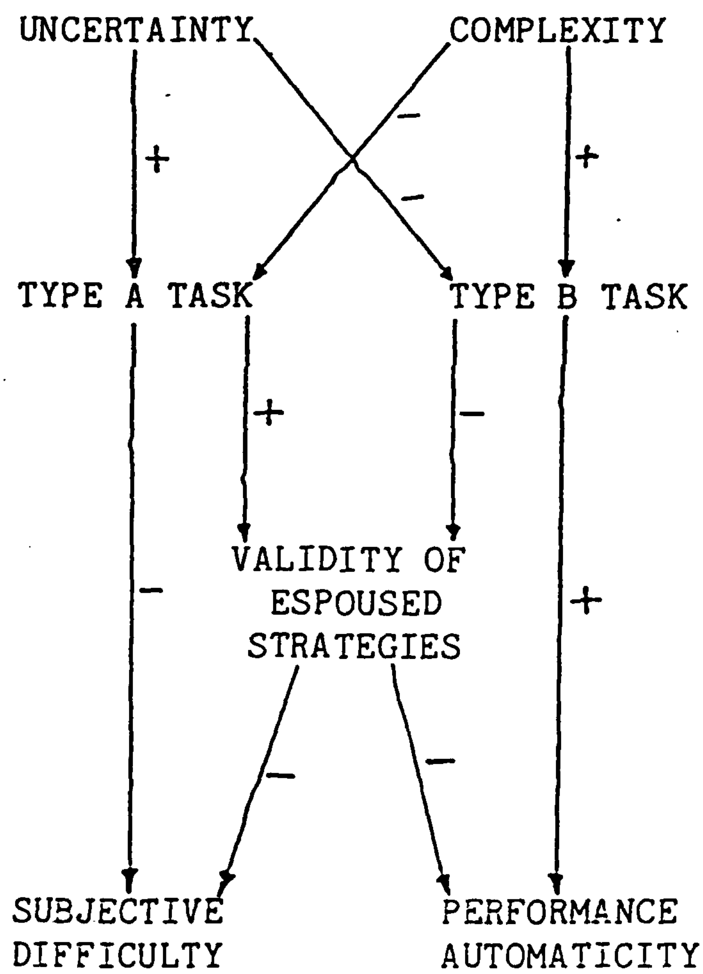

Figure 10-1

validity of explicit information derived from this type of processing is likely to be very high (i.e., correspond to actual performance). In contrast, if a task is very complex, the number of parameters may exceed the capacity of attentional mechanisms. Similarly, if a task is certain, the employment of attentional mechanisms becomes unnecessary. In either case the validity of espoused strategies would decrease. S trategic validity, in turn, mediates the effects of task structure (complexity and uncer'ainty) on the two remaining outcomes: rated difficulty and performance automaticity.

If the explicit knowledge to which subjects have access is inaccurate (as in the case of the complex but certain task), it is reasonable to assume that interfering with the application of this mis-information might actually improve performance. This is reflected by the negative relation between strategic validity and performance automaticity. The model again offers two plausible explanations. The first explanation is that certainty allows automaticity. This is well-established and widely-accepted (e.g., Shiffrin & Schnieder, 1977). The alternative influence is that complexity (and not simplicity) also contributes to performance automaticity. Justification for this influence is less obvious but equally plausible. If a task is simple and explicit knowledge is valid, the allocation of additional attentional resources (i.e., trying harder) is likely to enhance performance. If as Broadbent or Reber suggests, explicit and implicit modes of information processing are counter-dependent, reliance on explicit processing would diminish subjects' reliance on implicit processing. Thus, it is more likely complex tasks will evoke implicit processing and

come to be performed automatically. In fact, Edwards (1979) suggests tasks of increased complexity induce shifts to more passive forms of cognitive processing.

The differential difficulty subjects ascribed to the two tasks also has several interesting explanations. The positive relationship between complexity and rated difficulty is intuitive. This relationship, in turn, implies the negative relationship between the validity of espoused strategies and rated difficulty. Subjects are likely to rate tasks which they cannot explain as being more difficult. The negative relation between uncertainty and rated difficulty indicates the more uncertain task was considered to be less difficult. From this perspective, rated difficulty might reflect the responsibility subjects felt for the task. To the extent they believed outcomes were determined by chance rather than skill or their own effort, they may have rated the task as being less difficult.

The foregoing discussions should have made one priority for future research obvious. The results suggest two explanations for each relation between dependent measures. The two hypothetical dimensions used to differentiate the tasks (viz., complexity and uncertainty) were confounded. The two dimensions were perfectly negatively related (the presence of one necessarily involved the absence of the other). Although several small adjustments were made between experiments, neither complexity nor uncertainty was directly manipulated or specifically examined. Priority in these experiments was given to establishing differences between the two task types. Comparisons between the two tasks show the combined effects of the factors. Independent manipulation of either or both

dimensions within the respective tasks is necessary to identify the separate influences of the two task dimensions.

Theoretically either uncertainty or complexity could be manipulated within either task. Changing the number of task parameters, however, is very difficult to accomplish without changing the task itself. Decreasing the number of targets particularly in the Type B (kayak) task would reduce complexity somewhat. Complexity in the Type A task might be increased by introducing additional targets. Another way to increase complexity in the Type A task would be to introduce conditional criteria for scoring (i.e., plankton "hits could only be scored if the whale was also turning right).

Uncertainty manipulations involve changing the frequency with which task parameters must be specified without changing the number of parameters. Tasks in which only the uncertainty is manipulated remain phenomenologically similar - only the predictability of the target's activity is altered. For the Type A task, deleting alternative starting directions and locations would reduce uncertainty. The period of the plankton's movements could also be reduced from the present 217 cycles to repeated series of moves every 10 or 20 cycles. For the Type B task, uncertainty could be increased in two ways. The time and location of target generation could be altered from one trial to the next. It would also be possible to introduce occasional random movements of the targets so their pursuit path would be less predictable after they were on the screen.

In addition to investigating the separate effects of complexity and uncertainty, there are several other areas which

appear amenable to study using the approach developed here. The direct comparison of performance and verbal reports concerning two structurally different tasks yielded several somewhat counter intuitive results. The Type B, kayak task was particularly interesting. This complex task appears to require many of the same intangible capabilities such as judgement and intuition often cited as being critical to the skillful operation of complex systems (e.g., Roscoe & North, 1980; Jensen, 1982). However, several aspects of the performance of this task were somewhat surprising: the inconsistency of verbal explanations and performance, the relatively rapid automatization of the task and evidence suggesting not only independence but facilitation from certain verbal side tasks. To the extent these results can be generalized to real-life performance problems, they provide a possible explanation (and partial justification) for the scepticism with which many of those who are responsible for developing and operating complex systems view the results of many traditional laboratory experiments.

Areas of particular interest might be the relative effectiveness of alternative forms of instruction or modes of processing. Studies reported by Berry and Broadbent (1984) suggest that although verbal instruction improves explicit knowledge, it has no impact on performance unless it is combined with concurrent verbalization. Similar investigations of the two tasks involved in the computer game would have interesting theoretical implications and also be directly applicable to the development of training syllabi for the operation of complex systems. The improvements in performance from traditional active verbal instruction and passive non-verbal observational learning could also be compared directly.

A related issue of interest is the separation of objective validity from the functional utility of verbal instructions. It is possible instructions which have the most positive effects on task performance will not be those that are the most accurate.

This study also suggests the opportunity for further research involving individual differences. None of the measures of game performance showed consistent relations with any of the standard measures of individual differences. Likewise, the operational success of pilots often shows nearly no correlation with the individual difference measures most predictive of performance early in flight training such as reaction time, hand-eye coordination, or intelligence (Fleishman, 1958, 1972; North, Gopher & Roscoe, 1979; Jensen, 1982; Gopher, 1982). It is at least possible that certain aspects of the game (i.e., performance ratios) might provide viable measures of factors which are often subjectively identified as being the most important determinants of long term flying success (e.g., judgement or intuition).

The relative effects of alternative learning conditions are also important. Reber and Kassin (1980) suggest implicit and explicit modes of information processing result in substantial differences in both current performance and the accuracy of subsequent verbal reports. From the studies reported here, the explicit mode of processing would appear to be the most appropriate for the Type A task but the Type B task should be both performed and learned better under implicit conditions. This hypothesis could be directly tested by using different instructions to induce the alternative modes of information processing (e.g., suggesting subjects should discover and employ "the rules" underlying the task

would exert strong pressure toward the explicit mode of processing).

Although this thesis has been exclusively concerned with the performance of individual subjects, the task itself could be easily adapted to study group performance. Each of the four discrete input keys could be separated and given to members of a group. The task would remain the same but would require considerable co-ordination and co-operation to be performed effectively. Group factors such as compatibility, cohesiveness, group structure and leadership styles might each be reflected in differential performance on the two tasks or at different levels within a single task. The issue of ecological validity is at least as relevant to the study of group performance as it is to individual performance. To the extent the arcade game format has been successfully applied here, it might be expected to provide a useful adjunct to the empirical study of task groups as well.

Overall conclusions, their theoretical implications and opportunities for further research have been presented in this final chapter. Perhaps the most important conclusion, however, is the most general one: substantively different tasks involve different intermediate cognitive processes. The accuracy of subjects' verbal protocols, their subjective ratings and the performance characteristics of the tasks themselves all reflect substantial differences. The type of task, amount of practice and type (or difficulty) of the side task were all important determinants of how task-relevant information appeared to be processed. The popular assumptions that 1) explicit knowledge is a fully-contained subset of implicit knowledge and 2) the application

of additional resources (i.e., time, effort, attention or specific processing mechanisms) is always facilitatory, both appear to be of less than universal validity. Further research is needed to identify the independent effects of complexity and uncertainty. There are also considerable opportunities for adapting the game and general approach to questions concerning education and training, individual differences and group processes.

10:5 POST SCRIPT

It was suggested earlier that a great deal of procedural information might be symbolically represented in the form of a verbal adage. A proverb, borrowed from a boyhood in the hills of Kentucky, captures the message this thesis attempts to explicate:

It ain't so much the things a man don't know
vot gits him in trouble;
it's the things he knows
that jest ain't so.

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APPENDIX A

ANNOTATED BASIC LISTING OF SAVE THE WHALE COMPUTER GAME

```
   5 REM "whale"
   6 POKE 51900,(PEEK 51900)+1)
  10 LET c$="▲": LET w=5
  12 FOR c=0 TO 31: POKE (50000+
(10*c)),0: NEXT c
  14 FOR c=0 TO 25: POKE (51000-
(10*c)),0: NEXT c
  15 FOR c=0 TO 10: POKE (52000+
(10*c)),0: NEXT c
  16 LET kd=0
```

Set discrete memory locations to zero

```
  17 FOR c=0 TO 10: POKE (50150+
(10*c)),100: NEXT c
  20 IF PEEK 51900=1 OR PEEK 519
00=6 OR PEEK 51900=8 OR PEEK 519
00=11 OR PEEK 51900=15 OR PEEK 5
1900=16 THEN POKE 50310,2: GO TO
 100
  21 IF PEEK 51900=2 OR PEEK 519
00=4 OR PEEK 51900=9 OR PEEK 519
00=12 OR PEEK 51900=13 OR PEEK 5
1900=17 THEN POKE 50310,0: GO TO
 100
  22 POKE 50310,4
```

Counterbalanced speed presentation

```
 100 POKE USR "l"+0,BIN 00000000
: REM whale"tracking screen left
 110 POKE USR "l"+1,BIN 00000000
 120 POKE USR "l"+2,BIN 00110000
 130 POKE USR "l"+3,BIN 01111001
 140 POKE USR "l"+4,BIN 11111101
 150 POKE USR "l"+5,BIN 11101111
 160 POKE USR "l"+6,BIN 11111001
 170 POKE USR "l"+7,BIN 00000001
```

Graphic: Whale left

```
 200 POKE USR "r"+0,BIN 00000000
: REM whale tracking screen righ
t
 210 POKE USR "r"+1,BIN 00000000
 220 POKE USR "r"+2,BIN 00001100
 230 POKE USR "r"+3,BIN 10011110
 240 POKE USR "r"+4,BIN 10111111
 250 POKE USR "r"+5,BIN 11110111
 260 POKE USR "r"+6,BIN 10011111
 270 POKE USR "r"+7,BIN 10000000
```

Graphic: Whale right

```
 300 POKE USR "u"+0,BIN 00111100
: REM whale tracking up screen
 310 POKE USR "u"+1,BIN 00111100
 320 POKE USR "u"+2,BIN 01111110
 330 POKE USR "u"+3,BIN 11111111
 340 POKE USR "u"+4,BIN 10111101
 350 POKE USR "u"+5,BIN 00011000
 360 POKE USR "u"+6,BIN 00011000
 370 POKE USR "u"+7,BIN 00111100
```

Graphic: Whale up

```
 400 POKE USR "d"+0,BIN 00111100
: REM whale tracking down screen
 410 POKE USR "d"+1,BIN 00011000
 420 POKE USR "d"+2,BIN 00011000
 430 POKE USR "d"+3,BIN 10111101
 440 POKE USR "d"+4,BIN 11111111
 450 POKE USR "d"+5,BIN 01111110
 460 POKE USR "d"+6,BIN 00111100
 470 POKE USR "d"+7,BIN 00111100
```

Graphic: Whale down

```
500 POKE USR "i"+0,BIN 00100000
: REM iceberg
510 POKE USR "i"+1,BIN 00110000
520 POKE USR "i"+2,BIN 00110000
530 POKE USR "i"+3,BIN 00111000
540 POKE USR "i"+4,BIN 01111000
550 POKE USR "i"+5,BIN 01111100
560 POKE USR "i"+6,BIN 11111100
570 POKE USR "i"+7,BIN 11111110
600 POKE USR "p"+0,BIN 00111100
: REM plankton
610 POKE USR "p"+1,BIN 01000010
620 POKE USR "p"+2,BIN 10011001
630 POKE USR "p"+3,BIN 10111101
640 POKE USR "p"+4,BIN 10111101
650 POKE USR "p"+5,BIN 10011001
660 POKE USR "p"+6,BIN 01000010
670 POKE USR "p"+7,BIN 00111100
680 POKE USR "a"+0,BIN 00000000
: REM kayak
681 POKE USR "a"+1,BIN 00000010
682 POKE USR "a"+2,BIN 00011010
683 POKE USR "a"+3,BIN 00011100
684 POKE USR "a"+4,BIN 01111111
685 POKE USR "a"+5,BIN 00111100
686 POKE USR "a"+6,BIN 00010000
687 POKE USR "a"+7,BIN 00100000
0
700 POKE USR "k"+0,BIN 00000000
: REM kayak
710 POKE USR "k"+1,BIN 10000000
720 POKE USR "k"+2,BIN 01011000
730 POKE USR "k"+3,BIN 00111000
740 POKE USR "k"+4,BIN 11111110
750 POKE USR "k"+5,BIN 00111100
760 POKE USR "k"+6,BIN 00001000
770 POKE USR "k"+7,BIN 00000100
771 IF PEEK 51900=19 THEN CLS :
BORDER 2: PAPER 7: INK 1: PRINT
;AT 10,10; BRIGHT 1; FLASH 1;"G
AME OVER": STOP
774 IF PEEK 51900=2 OR PEEK 519
00=6 OR PEEK 51900=10 OR PEEK 51
900=14 OR PEEK 51900=18 THEN LET
a1=9: LET b1=15: GO TO 778
775 IF PEEK 51900=1 OR PEEK 519
00=5 OR PEEK 51900=9 OR PEEK 519
00=13 OR PEEK 51900=17 THEN LET
a1=10: LET b1=19: GO TO 778
776 IF PEEK 51900=3 OR PEEK 519
00=7 OR PEEK 51900=11 OR PEEK 51
900=15 THEN LET a1=9: LET b1=18:
GO TO 778
777 LET a1=10: LET b1=17
778 IF PEEK 51900=1 OR PEEK 519
00=4 OR PEEK 51900=7 OR PEEK 519
00=10 OR PEEK 51900=13 OR PEEK 5
1900=16 THEN POKE 50090,100: POK
E 50080,10: GO TO 880
779 IF PEEK 51900=2 OR PEEK 519
00=5 OR PEEK 51900=8 OR PEEK 519
00=11 OR PEEK 51900=14 OR PEEK 5
1900=17 THEN POKE 50090,50: POKE
50080,50: GO TO 880
780 IF PEEK 51900=3 OR PEEK 519
00=6 OR PEEK 51900=9 OR PEEK 519
00=12 OR PEEK 51900=15 OR PEEK 5
1900=18 THEN POKE 50090,10: POKE
50080,100: GO TO 880
790 IF PEEK 51900=1 OR PEEK 519
00=3 OR 51900=5 OR PEEK 51900=7
OR 51900=9 OR PEEK 51900=11 OR P
EEK 51900=13 OR PEEK 51900=15 OR
PEEK 51900=17 [illegible]
```

Graphic: Iceberg

Graphic: Plankton

Graphic: Kayak I

Graphic: Kayak II

Initialize plankton at different locations

Set priority rotation

```
910 BORDER 7: PAPER 7: INK 0: [illegible]
[illegible] PRINT [illegible] WHALE IS
NOT ALONE"; "Eskimoes in kayaks
"; INK 2;" "; INK 0;" are after
 your whale "; INK 1;" "; INK 0
;". To save it, you must make
them wreck their    kayaks on
the icebergs."; INK 7;" "; PR
INT
 912 PRINT ; INK 0 "Each time on
e of the kayaks     crashes, the
  computer beeps    once and you
 score but each times kayak reac
hes (and harpoons) the whale yo
u lose points." "The ocean also
has a small mass of plankton ";
INK 4; BRIGHT 1; FLASH 1;"@"; IN
K 0; BRIGHT 0; FLASH 0;" for you
r whale to eat.  Get  your whale
 to eat as much as it can: the c
omputer    beeps and you score m
ore points."
 913 PRINT ''"  Press ENTER to c
ontinue."; PAUSE 10000: CLS
1010 PRINT "Your score will be d
isplayed at the top of the scree
n throughoutthe game.  The objec
t is to makeas many points as po
ssible. Eachgame takes about 3 m
inutes."
1031 PRINT : PRINT "Each  time a
 kayak  crashes  yougain ";PEEK
50090;TAB 8;"points but each tim
e a  kayak harpoons the whale, y
ou   lose ";PEEK 50090;" points.
"
1032 IF PEEK 50090=10 THEN PRINT
 "Each time the whale chomps a b
itof plankton, you earn 100 pts.
  You should concentrate on eati
ngplankton and not worry too muc
h about the kayaks.": GO TO 1050
1033 IF PEEK 50090=100 THEN PRIN
T "Each time the whale chomps a
bitof plankton, you receive 10 p
ts.You should concentrate on the
   kayaks.  Only eat plankton wh
en it is safe to do so."
1044 IF PEEK 50090=50 THEN PRINT
 "Each time the whale chomps a b
itof plankton, you receive 50 pt
s.": PRINT "You should concentra
te on both  tasks about equally.
"
1050 PRINT ''"Hint: the kayaks al
ways move towards the whale, so
 the way to  make them crash is
to insure thewhale is on the opp
osite side ofthe nearest cluster
 of icebergs.": PAUSE 10000: BOR
DER 1: PAPER 5: CLS
2000 RANDOMIZE 4: REM print iceb
ergs in position
2030 FOR i=1 TO 20: LET ix=INT (
((SGN (RND-.5) * (RND*4)+3))+15)
: LET iy=INT ((SGN (RND-.5))*((
RND*4)+2))+10): BORDER 1: PAPER
5: INK 7: PRINT AT iy,ix;" ": NE
XT i: PRINT AT 15,21; INK 5;" "
[illegible] LET [illegible]=20: LET ww=15
[illegible]
```

Print general playing instructions

Print priority-specific instructions

Generate and Print iceberg clusters

```
3000 GO SUB 4200
3001 IF PEEK 52020 250 THEN GO T
O 4290
3009 POKE 52080,0: LET ε=0: LET
r=0: POKE 50105,0: IF PEEK 50200
>50 THEN GO TO 3019
3010 LET r=SGN ((PEEK 50150)-ww)
: LET ε=SGN ((PEEK 50200)-wh): P
RINT AT PEEK 50200,PEEK 50150; I
NK 5;" ": POKE 50150,INT ((PEEK
50150)-r): POKE 50200,INT ((PEEK
 50200)-ε): POKE 52080,((PEEK 52
080)+1): IF ATTR ((PEEK 50200),P
EEK 50150)=47 THEN LET kd=kd+1
BEEP .05,12: POKE 50200,100: POK
E 52080,((PEEK 52080)-1): GO TO
3019
3011 IF ATTR (PEEK 50200,PEEK 50
150)=41 THEN POKE 50200,100: BEE
P .05,15: BEEP .05,13: BEEP .05,
5: LET kd=kd-1: GO TO 3019
3012 PRINT AT PEEK 50200,PEEK 50
150; INK 2;"*"
3013 IF (ABS ε+ABS r)>1 THEN POK
E 52030,((PEEK 52030)+1)
3014 IF PEEK 52020>2*(INT ((PEEK
 52020)/2)) THEN PRINT AT PEEK 5
0200,PEEK 50150; INK 2;"*"
3019 IF PEEK 50210>50 THEN GO TO
 3029
3020 LET r=SGN ((PEEK 50160)-ww)
: LET ε=SGN ((PEEK 50210)-wh): P
RINT AT PEEK 50210,PEEK 50160; I
NK 5;" ": POKE 50160,INT ((PEEK
50160)-r): POKE 50210,INT ((PEEK
 50210)-ε): POKE 52080,((PEEK 52
080)+1): IF ATTR (PEEK 50210,PEE
K 50160)=47 THEN POKE 50210,100:
 LET kd=kd+1: BEEP .05,12: POKE
52080,((PEEK 52080)-1): GO TO 30
29
3021 IF ATTR (PEEK 50210,PEEK 50
160)=41 THEN POKE 50210,100: BEE
P .05,15: BEEP .05,13: BEEP .05,
5: LET kd=kd-1: GO TO 3029
3022 PRINT AT PEEK 50210,PEEK 50
160; INK 2;"*"
3023 IF (ABS ε+ABS r)>1 THEN POK
E 52030,((PEEK 52030)+1)
3024 IF PEEK 52020>2*(INT ((PEEK
 52020)/2)) THEN PRINT AT PEEK 5
0210,PEEK 50160; INK 2;"*"
3029 IF PEEK 50220>50 THEN GO TO
 3039
3030 LET r=SGN ((PEEK 50170)-ww)
: LET ε=SGN ((PEEK 50220)-wh): P
RINT AT PEEK 50220,PEEK 50170; I
NK 5;" ": POKE 50170,INT ((PEEK
50170)-r): POKE 50220,INT ((PEEK
 50220)-ε): POKE 52080,((PEEK 52
080)+1): IF ATTR (PEEK 50220,PEE
K 50170)=47 THEN LET kd=kd+1: BE
EP .05,12: POKE 50220,100: POKE
52080,((PEEK 52080)-1): GO TO 30
39
3031 IF ATTR (PEEK 50220,PEEK 50
170)=41 THEN POKE 50220,100: BEE
P .05,15: BEEP .05,13: BEEP .05,
5: LET kd=kd-1: GO TO 3039
3032 PRINT AT PEEK 50220,PEEK 50
170; INK 2;"*"
3033 IF (ABS ε+ABS r)>1 THEN POK
E 52030,((PEEK 52030)+1)
3034 IF PEEK 52020>2*(INT ((PEEK
 52020)/2)) THEN PRINT AT PEEK 5
0220,PEEK 50170; INK 2;"*"
3039 IF PEEK 50230>50 THEN GO TO
 3049
```

Kayak 1 Procedures: compute direction to whale, check for icebergs, check for whale then print kayak I then II.

Procedures for Kayak 2

Procedures for Kayak 3

Procedures for Kayak 4

```
3040 LET r=SGN ((PEEK 50180)-ww)
: LET s=SGN ((PEEK 50230)-wh): P
RINT AT PEEK 50230,PEEK 50180; I
NK 5;" ": POKE 50180,INT ((PEEK
50180)-r): POKE 50230,INT ((PEEK
 50230)-s): POKE 52080,((PEEK 52
080)+1): IF ATTR (PEEK 50230,PEE
K 50180)=47 THEN POKE 50230,100:
 LET kd=kd+1: BEEP .05,12: POKE
52080,((PEEK 52080)-1): GO TO 30
49
3041 IF ATTR (PEEK 50230,PEEK 50
180)=41 THEN POKE 50230,100: BEE
P .05,15: BEEP .05,13: BEEP .05,
5: LET kd=kd-1: GO TO 3049
3042 PRINT AT PEEK 50230,PEEK 50
180; INK 2;"✦"
3043 IF (ABS s+ABS r)>1 THEN POK
E 52030,((PEEK 52030)+1)
3044 IF PEEK 52020>2*(INT ((PEEK
 52020)/2)) THEN PRINT AT PEEK 5
0230,PEEK 50180; INK 2;"✦"
3049 IF PEEK 50240>50 THEN GO TO
 3055
```

Procedures for Kayak 5

```
3050 LET r=SGN ((PEEK 50190)-ww)
: LET s=SGN ((PEEK 50240)-wh): P
RINT AT PEEK 50240,PEEK 50190; I
NK 5;" ": POKE 50190,INT ((PEEK
50190)-r): POKE 50240,INT ((PEEK
 50240)-s): POKE 52080,((PEEK 52
080)+1): IF ATTR (PEEK 50240,PEE
K 50190)=47 THEN POKE 50240,100:
 BEEP .05,12: LET kd=kd+1: POKE
52080,((PEEK 52080)-1): GO TO 30
55
3051 IF ATTR (PEEK 50240,PEEK 50
190)=41 THEN POKE 50240,100: BEE
P .05,15: BEEP .05,13: BEEP .05,
5: LET kd=kd-1: GO TO 3055
3052 PRINT AT PEEK 50240,PEEK 50
190; INK 2;"✦"
3053 IF (ABS s+ABS r)>1 THEN POK
E 52030,((PEEK 52030)+1)
3054 IF PEEK 52020>2*(INT ((PEEK
 52020)/2)) THEN PRINT AT PEEK 5
0240,PEEK 50190; INK 2;"✦"
3055 LET b$=INKEY$: POKE 50105,k
d: POKE 50040,PEEK 52080
```

Compute pkt's next position

```
3100 LET a1=a1+INT ((.1-(PEEK 52
070/1.43))+(((PEEK 52020/7)-INT
(PEEK 52020/7))+((PEEK 52020/3)-
INT (PEEK 52020/3))))
3101 LET b1=b1+INT ((((PEEK 5202
0/2)-INT (PEEK 52020/2))+((PEEK
52020/4)-INT (PEEK 52020/4))+((P
EEK 52020/7)-INT (PEEK 52020/7))
)-.45)
```

Prevent whale from crossing screen border

```
3102 IF wh=0 THEN LET wh=1: POKE
 50130,(PEEK 50130)-1: GO TO 315
8
3103 IF wh=21 THEN LET wh=20: PO
KE 50130,(PEEK 50130)+1: GO TO 3
158
3104 IF ww=0 THEN LET ww=1: POKE
 50130,(PEEK 50130)-1: GO TO 315
8
3105 IF ww=31 THEN LET ww=30: PO
KE 50130,(PEEK 50130)+1: GO TO 3
158
```

Time sink

```
3158 IF PEEK 50210>0 THEN FOR i=
1 TO PEEK 50210: PRINT AT 0,0; I
NK 5;" ": NEXT i
3159 POKE 52020,(PEEK 52020)+1:
 POKE 50210,0: IF PEEK
52020=213 THEN POKE 52020,213
```

```
3150 LET a$=INKEY$  REM move wha
le
3180 IF a$="2" THEN LET m=7: POK
E 50110,1: GO TO 3250
3190 IF a$="s" THEN LET m=8: POK
E 50110,1: GO TO 3250
3200 IF a$="q" THEN LET m=5: POK
E 50110,1: GO TO 3250
3210 IF a$="e" THEN LET m=3: POK
E 50110,1: GO TO 3250
3220 POKE 50110,0
3250 LET d$=c$: LET wh=wh+(m=5)-
(m=7): LET ww=ww+(m=3)-(m=5): LE
T c$=("♣" AND a$="2")+("♠" AND a
$="e")+("♣" AND a$="s")+("♠" AND
 a$="q")
3255 IF c$=d$ THEN POKE 52050,((
PEEK 52050)+1)
3260 IF c$="" THEN LET c$=d$
3280 IF ATTR (wh,ww)=47 THEN POK
E 50060,1: GO TO 3290
3285 POKE 50060,0
3295 POKE 50050,0
3300 POKE 50020,wh: POKE 50030,w
w: POKE 50000,a1: POKE 50010,b1
3325 LET l=USR 55000
3327 IF a$=b$ OR a$="" THEN POKE
 52000,((PEEK 52000)+1)
3330 PRINT AT wh,ww; INK 1;c$
3350 IF a1<2 THEN POKE 52070,0
3360 IF a1>19 THEN POKE 52070,1
3380 IF b1>29 THEN LET b1=1
3500 GO TO 3000
4200 REM generate kiyaks at one
of five locations
4203 RANDOMIZE (80+PEEK 52020)
4210 IF PEEK 50200>50 AND RND<.0
2 THEN POKE 50200,0: POKE 50150,
10: PRINT AT 0,10; INK 2;"✦": PO
KE 52060,((PEEK 52060)+1)
4220 IF PEEK 50210>50 AND RND<.0
2 THEN POKE 50210,0: POKE 50160,
20: PRINT AT 0,20; INK 2;"✦": PO
KE 52060,((PEEK 52060)+1)
4230 IF PEEK 50220>50 AND RND<.0
2 THEN POKE 50220,10: POKE 50170
,0: PRINT AT 10,0; INK 2;"✦": PO
KE 52060,((PEEK 52060)+1)
4240 IF PEEK 50230>50 AND RND<.0
2 THEN POKE 50230,10: POKE 50180
,31: PRINT AT 10,31; INK 2;"✦":
POKE 52060,((PEEK 52060)+1)
4250 IF PEEK 50240>50 AND RND<.0
5 THEN POKE 50240,21: POKE 50190
,15: PRINT AT 21,15; INK 2;"✦":
POKE 52060,((PEEK 52060)+1)
4400 RETURN
4590 LET t=PEEK 23672: LET tt=PE
EK 23673: LET time=t-255+tt: 50
5055 PAUSE 1000
```

Read subject's input from keyboard and compute location and depiction of whale

Activate Pkt from machine code

Reroute border

"Randomly" generate kayaks at each of five border locations

Compute total trial time

Generate end of trial screen display

```
5950 CLS
6000 PRINT            END OF TRIAL
';PEEK 51900
6010 PRINT '  "Relax, your whale
is resting      for a minute."
6020 PRINT ' '"It ate ";PEEK 5102
0;" tons of plankton.": PRINT "A
t ";PEEK 50080;" pts/ton, that's
 ";PEEK 50080*PEEK 51020;" pts."
6025 IF PEEK 51180>50 THEN GO TO
 6050
6030 PRINT ''PEEK 52060;TAB 3;"K
ayaks were launched."';(((PEEK 5
2060)-(PEEK 52080)+PEEK 51180)/2
);TAB 3;"crashed into icebergs."
';(((PEEK 52060)-(PEEK 52080)-PE
EK 51180)/2);TAB 3;"harpooned yo
ur whale, and"';(PEEK 52080);TAB
 3;"is still paddling."'"That's
";((PEEK 50090)*PEEK 51180);" po
ints."''''"TOTAL SCORE = "; BRIGH
T 1; FLASH 1;PEEK 51180*(PEEK 50
090)+PEEK 50080*PEEK 51020: GO T
O 6100
6050 PRINT ''(PEEK 52060);TAB 3;
"Kayaks were launched."';(((PEEK
 52060)-(PEEK 52080)+(PEEK 51180
-256))/2);TAB 3;"crashed into ic
ebergs."';(((PEEK 52060)-(PEEK 5
2080)-(PEEK 51180-256))/2);TAB 3
;"harpooned your whale, and"';PE
EK 52080;TAB 3;"is still paddlin
g."'"That's ";((PEEK 50090)*(PEE
K 51180-256));" points."''''"TOTA
L SCORE = "; BRIGHT 1; FLASH 1;(
PEEK 51180-256)*(PEEK 50090)+PEE
K 50080*PEEK 51020
```

Generate end of trial data listing

```
6100 LPRINT "        END OF RUN DA
TA"
6103 LPRINT PEEK 51900;TAB 10;PE
EK 50310;TAB 20;PEEK 50080
6105 LPRINT ;TAB 5;(PEEK 51080);
TAB 10;PEEK 51090;TAB 15;PEEK 51
100;TAB 20;PEEK 51110;TAB 25;PEE
K 51140;TAB 5;(218-PEEK 51230);T
AB 10;(PEEK 51190-(PEEK 52050));
TAB 15;PEEK 52050;TAB 20;PEEK 52
030;TAB 25;(PEEK 51040+(2*PEEK 5
1050)+(3*PEEK 51060)+(4*PEEK 510
70));(INT ((time/217)*1000));TAB
 5;PEEK 51020;TAB 10;PEEK 51130;
TAB 15;PEEK 50130;
6106 IF PEEK 51180>50 THEN LPRIN
T TAB 20;((PEEK 52060+PEEK 51180
-256)/2);TAB 25;(PEEK 52060);TAB
 8;PEEK 51020;TAB 13;PEEK 51200-
PEEK 51020;TAB 18;PEEK 51210;TAB
 23;PEEK 51220: GO TO 6110
6107 LPRINT TAB 20;((PEEK 52060+
PEEK 51180)/2);TAB 25;(PEEK 5206
0);TAB 8;PEEK 51020;TAB 13;PEEK
51200-PEEK 51020;TAB 18;PEEK 512
10;TAB 23;PEEK 51220
6110 LPRINT (218-PEEK 52000) '
6130 INPUT "ENTER 1 to continue"
;X$
6131 IF X$="0" THEN GO TO 6100
6132 IF X$="1" THEN GO TO 9
6133 IF X$<>"0" AND X$<>"1" THEN
 GO TO 6130
9999 LOAD *"m";2;"WMC"CODE 55000
,8500
```

APPENDIX B

POST-GAME COMPUTER QUESTIONS

QUESTION ONE

Which of the following is most like the whale in the game ?

a.

b.

c.

d. none of the above.

QUESTION TWO

Which of the following is most like the plankton in the game ?

a b c d none of these

QUESTION THREE

Which of the following is most like the kayaks?

a.

b.

c.

d. none of the above

QUESTION FOUR

Which of the following is most like the icebergs in the game ?

a b c d different.as

QUESTION FIVE

The beep when a kayak crashed was higher (in pitch) than when the whale ate plankton.

a. TRUE

b. FALSE

QUESTION SIX

The kayaks could only move diagonally.

a. TRUE

b. FALSE

QUESTION SEVEN

The kayaks appeared in the same places, at the same times, and in the same order on each trial.

a. TRUE

b. FALSE

QUESTION EIGHT

The whale could move diagonally if two buttons were held down at the same time.

a. TRUE

(→) b. FALSE

QUESTION NINE

If the whale went off the screen at one of the borders it reappeared at the opposite border.

a. TRUE

→ b. FALSE

QUESTION TEN

How many icebergs were there at the start of each trial?

a. 10

b. 15

→ c. 18

d. more than 20

e. the number was different on different trials

QUESTION ELEVEN

The kayaks came from:

a. anywhere along the screen border .

b. from only three locations.

→ c. from five different places.

d. from seven different locations.

QUESTION TWELVE

Which of the following best describes the plankton's movement?

(→) a. slightly random; tended to follow the same zig-zag path to the right each time.

b. generally random; drifted to the right but moved upwards or downwards at random.

c. completely random; different patterns each trial.

QUESTION THIRTEEN

In addition to being able to move diagonally the kayaks could also move more quickly than the whale.

a. TRUE

→ b. FALSE

QUESTION FOURTEEN

When plankton was worth 50 pts a bite, how many pts were lost each time the whale was harpooned?

a. 10 points

b. 25 points

c. 50 points

d. 100 points

QUESTION FIFTEEN

What happened when a kayak and the plankton were located in the same position at the same time?

a. the computer beeped and the kayak disappeared.

b. the computer beeped and the plankton disappeared.

c. the whale disappeared

d. none of the above.

QUESTION SIXTEEN

The plankton started at the same place and followed the same path on each trial.

a. TRUE

b. FALSE

QUESTION SEVENTEEN

If the plankton moved into the space occupied by the whale (instead of the whale moving into the plankton's space), no points were scored.

a. TRUE

b. FALSE

QUESTION EIGHTEEN

To wreck both kayaks the whale must:

a. turn left immediately then right after passing the iceberg

b. continue straight ahead, and turn left as soon as it is clear of the icebergs

c. reverse direction rapidly several times

d. none of the above; it is not possible to wreck both kayaks.

QUESTION NINETEEN

To wreck the kayak the whale must:

a. do nothing

b. turn right (away from kayak) immediately

c. reverse direction rapidly several times

d. none of the above; it is not possible to wreck the kayak.

QUESTION TWENTY

If wrecking the kayak is worth 50 points, the whale should:

a. turn left (upwards)

→ b. continue ahead (do nothing)

c. reverse direction

d. turn right (downwards)

QUESTION TWENTY-ONE

If wrecking the kayak is worth 5 points, the whale should:

a. turn left (upwards)

b. continue ahead (do nothing)

c. reverse direction

(→)d. turn right (downwards)

QUESTION TWENTY-TWO

The best way to force the kayaks to crash was to:

a. always turn away from them as soon as they were identified

b. allign the whale with the kayak either vertically or horizontally

c. do nothing; they frequently crashed on their own

d. reverse direction rapidly so they would miss the whale

QUESTION TWENTY-THREE

When the mass of plankton approached a cluster of icebergs it:

a. tended to 'go around' the cluster.

→ b. appeared to 'go under' the icebergs (disappear and then reappear on the other side.

c. seemed to 'bounce off' the cluster (change course)

QUESTION TWENTY-FOUR

Which of the following best describes the noise the computer mae when a kayak harpooned the whale?

a. 2 beeps of the same pitch

b. 3 beeps of increasing pitch

→ c. 3 beeps of decreasing pitch

d. 4 beeps of varying pitch.

QUESTION TWENTY-FIVE

The plankton moved one space every cycle (it never remained in the same place).

a. TRUE

→ b. FALSE

APPENDIX C

SAVE THE WHALE

The following rules might apply to the whale's task of "eating plankton". In the first space write "+" for things you think the whale should do, "-" for things the whale should avoid doing, and "0" for things that don't matter. Next for the two most important rules, please put a "*"in the second space.

__ __ Eat icebergs
__ __ Stay near the plankton (in the general vicinity)
__ __ Stay near the center of the screen
__ __ Constantly turn toward the plankton (concentrate)
__ __ Know where the plankton is going and plan accordingly
__ __ Ignore the kayaks

The following rules might apply to the whale's kayak-crashing task. Please, follow the same instructions as before for the following "rules".

__ __ Eat icebergs
__ __ Turn away from the kayaks as soon as they appear
__ __ Stay near the center of the screen
__ __ Stay near one cluster of icebergs (don't move between clusters)
__ __ "Line-up" with the kayaks so they move horizontally or vertically
__ __ Ignore the plankton

There were three different priorities during the game. Using a "K" for the kayak priority trials, a "P" for the plankton priority trials, and an "E" for the equal priority trials, please rate each of these types of trials on the following scales:

Difficulty - the extent to which the total task demands exceeded your total capabilities; "hard to do"; requiring a great deal of effort.

Difficult 1 --------- 2 --------- 3 --------- 4 --------- 5 Easy

Complexity - hard to understand or explain; involves many activities or steps, very intricate, many things to be considered.

Complex 1 --------- 2 --------- 3 --------- 4 --------- 5 Simple

Uncertainty - hard to predict what will happen next, very doubtful, lacking in pattern, randomness.

Uncertain 1 --------- 2 --------- 3 --------- 4 --------- 5 Certain

END

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